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ENVIRONMENTAL HEALTH SERIES
Water Supply and Pollution Control

The Santee Recreation Project Santee, California

Summary Report, 1962 - 1964

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Cover photograph shows lakes as improved during 1964-65.

GPO 923-048-1

ERRATA SHEET

To Recipient of Santee Recreation Project Report:

This Environmental Health Series Report 999-WP27 summarizes the first phase of the investigations at Santee that were necessary to provide acceptance by both the health authority and the public for multiple recreational activities in this recreation facility. A second report will follow within a year and will cover the results of the complete virologic investigations, the swimming program conducted during the summer of 1965, and the continuing biological investigations.

Significant errata in this report are listed below:

1. Page 6, Figure 1: The sample point at Lake No. 2 should be identified as 7 and 7A

2. Page 33, Table 16: The footnote for this Table is in error. Actually, SHD identifies State Health Department results and CHD represents County Health Department results

3. Page 63, Figure 24: The unmarked slant hatched area should be labeled Residual.

THE SANTEE RECREATION PROJECT
SANTEE, CALIFORNIA

SUMMARY REPORT, 1962 — 1964

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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ABSTRACT

This paper presents the results of a study of the Santee, California, recreational lakes. These lakes were deliberately planned to utilize the community's reclaimed sewage effluent. The seven-agency cooperative study evaluated the fate of virus along with total and fecal coliform and fecal streptococci through the conventional secondary treatment process, the tertiary processes, and the recreational lakes. The correlating physical and chemical data have also been presented along with a biological study of the lakes and related land area. Discussions of eutrophication, vector control, epidemiology, and the social acceptance and ecology of the entire recreational park are developed. The study concludes that the treatment provided by intermittent sand filtration has met the nutrient requirements of the emerging ecology and that no health hazards have been demonstrated by the viral or other findings for the present recreational uses of boating and fishing.

THE SANTEE RECREATION PROJECT
SANTEE, CALIFORNIA

SUMMARY REPORT, 1962 — 1964

SUMMARY

The Santee County Water District has for the last 4 years successfully operated two limited-use recreational lakes supplied with a reclaimed waste water developed from the community's secondary sewage treatment plant. This report summarizes the cooperative study that was established as a requirement for the limited recreational use. The tertiary treatment required by the State and the County Health Department has proved to be an effective barrier for virus control in the recreational lakes even though large increases in viral concentrations were generated in the community by the feeding of Sabin oral polio vaccines. The tertiary soil treatment system employed has also been the effective system for control of nutrients at levels adaptable for both aesthetic acceptance and continuing fish propagation in spite of the shallow aquifer and limited under-ground travel. The large-percentage reductions obtained in the conventional activated-sludge treatment process emphasize the necessity for effective treatment ahead of the polishing processes.

Having the low-loaded Oxidation Pond follow secondary treatment has not provided much treatment in relation to land area used. It has provided satisfactory reductions in virus identifications and moderate removals of nitrogen, alkalinity, and bacteria. The Oxidation Pond had a distressed period during the winter months when overturning conditions prevail. Dissolved oxygen was depressed to very small concentrations and zooplankton came to the surface in large numbers. A true pulse of zooplankton occurred in the spring and resulted in algae as well as oxygen depletion. During these times, odor conditions have resulted from the Oxidation Pond. The Oxidation Pond was also a source of insects that could not be controlled by biological means.

The tertiary treatment provided by the soil was restricted by mounding in the shallow depth of the aquifer. Soil clogging also decreased percolation and required occasional scarification. The soil treatment was most effective in nutrient removal at lower spreading rates and only passed increased ammonia nitrogen and orthophosphate at higher rates.

The stream following percolation had its own distinctive biota when subject to continuous flow. This stream has also provided removals of some residual ammonia nitrogen and orthophosphate. Only ABS and COD entered the lakes at levels indicative of the water source.

The biological record for the recreational lakes showed productivity that kept dissolved-oxygen concentrations above 100 percent saturation at all times except in the October turnover period. A single kill of threadfin shad could not be related to chemical characteristics of the waste water. The lakes did not present an insect nuisance.

The record of immediate previous use of the waters provided for recreation at Santee could cast a public health significance on the occasional increased presence of indicator organisms in the water. The record shows appreciable bacterial counts on occasion in the lake waters, but the ratios of fecal coliform/coliform and fecal streptococci/fecal coliform are not normal for direct sewage contamination. Since no virus were found in lake waters, the public health significance of the residual coliform organisms can be established only by an epidemiological survey. The pilot epidemiological study produced evidence that has assisted in the development of plans to expand the recreation to possibly include swimming. It is probable that the additional control procedures necessary for keeping water clarity at safe levels for swimming will provide a margin of safety for virus and pathogen limitation.

CONCLUSIONS

1. This study has demonstrated the feasibility of using activated sludge, oxidation pond, and intermittent sand filtration treatment procedures for reclaiming a waste water for supplying recreational lakes.

2. The level of nutrients in the treated waste water has proved satisfactory for a balanced chain of producers and consumers that have successfully supported seven types of fish.

3. Health hazards of more intimate contact such as swimming in the reclaimed water cannot be demonstrated by the viral or other findings.

4. The bacterial concentrations in the recreational lake are more likely related to recontamination in the lake than to regrowth from sewage organisms, and it is recommended that this factor be proved or disproved by suitable epidemiological evaluation or other means.

5. Since continued enrichment of the recreational lakes may cause an upset that could damage the investment, the biological study should continue on an intermittent basis to assist in the further development of suitable management procedures.

INTRODUCTION

The Santee Recreation Project was designed to determine in the field the optimum procedures necessary to manage water quality through a waste treatment and water reclamation system supplying water for recreational lakes, recharge, and irrigation. The research project resulted from the need of the County and State Health authorities for information about the presence of viruses in reclaimed waters when the Santee County Water District proposed to use its well-treated effluent water for recreational lakes. The extent of the research incorporated in the final project was broadened to include, along with virus identification, related chemical, physical, and bacteriological pollution indicators as well as a start on an epidemiological record. Separate studies of hydrology, vector control, fish propagation, and aquatic biology were also set up to make more effective use of correlating data obtained originally for the virus study.

This report includes findings of all cooperating participants for the first 3 years of the study during which only non-water contact activities have been allowed. Changes in treatment have been made to improve water quality and to provide variations in the treatment process. The seven agencies that have participated in the study are the U. S. Public Health Service, California Department of Public Health, California Department of Water Resources, California Water Quality Control Board, California Department of Fish and Game, San Diego County Department of Public Health, and the Santee County Water District.

The San Diego Department of Public Health granted approval for non-water contact recreational use in April 1961, with the provision that a study of viruses in waste water be started. Chronology of significant events since then follows:

May	1961	Study requested by San Diego County Health Department.
June 24,	1961	Lake No. 4 was opened for use under County Health Department jurisdiction.
June	1961	Study program outlined by three health agencies. Fish planted in Lakes No. 3 and No. 4.
November	1961	Final plans for Santee Water Reclamation Study completed.
January	1962	Public Health Service Project Director on duty.
February	1962	First quarterly sampling. All flow to percolation area.
March	1962	Vector Control Study started.
April	1962	Memo of Understanding between six cooperating agencies completed.

April	1962	Spreading area changed from ridge and furrow to six 1/2-acre beds. Virus study contract between California Water Quality Control Board and San Diego County Department of Public Health approved.
July	1962	First virus samples obtained.
August	1962	Public Health Service Biologist on duty at Santee.
January	1963	Advisory Committee agrees on operating changes for second year and general plan for epidemiological study.
March	1963	Operations changed to divert part of the flow from Oxidation Pond 1 to Pond 2 with chlorination. Spreading area out of service.
April	1963	Spreading Basin returned to service, receiving part of the flow from Pond 1, without chlorination. Spreading area fenced, and chlorine contact chambers added at inlets of Lake 4 and Pond 2. Fish for Fun program started.
May	1963	Successful bass spawning observed.
June	1963	Laboratory building completed.
July	1963	Start of the pilot epidemiological survey.
December	1963	Lake 5 construction started.
May	1964	Special Epidemiological Advisory Committee appointed.
June	1964	Fishing program changed to allow consumption.
August	1964	Epidemiological Committee recommended swimming be permitted in separate swimming area.

PROJECT DESCRIPTION

The unincorporated community of Santee lies along the San Diego River Valley for a distance of 6 miles, beginning approximately 15 miles above the river mouth. It is located just north of the City of El Cajon and about 20 miles by road from downtown San Diego. The community is largely residential with only a few commercial establishments essential to community needs. There is no waste-producing industry.

Sycamore Creek, a tributary of the San Diego River, extends generally northward from the San Diego River channel and forms a canyon containing both the treatment plant for the community and the recreational lakes. There is subsurface flow in Sycamore Canyon but only occasional surface flow.

The floor of the canyon slopes upward to the north at 1 percent and narrows from approximately 2,000 feet in width at its mouth to

approximately 1,000 feet in width above the recreation lakes. The elevation of the plant is 325 feet. The canyon contains an alluvial fill 12 to 15 feet deep, deposited over sedimentary bedrock composed of siltstone and clayey sandstone, which serves to confine the underground stream. The area immediately upcanyon from the location of the sewage treatment plant has been extensively worked by a gravel-processing industry to a depth of from 10 to 12 feet. The remaining borrow pits have been reworked into level areas with earthen berms to provide oxidation ponds or lakes to receive the sewage treatment plant effluent. Areas farther upcanyon will continue to be worked as time goes by, and this will result in the creation of additional lakes. Figure 1 shows the location of the present lakes and treatment facilities. The area immediately to the east and west of the canyon is occupied by a development that contains about 1,700 residences.

The master plan for development of the canyon provides for a flood channel along the westerly boundary and a freeway along the easterly edge of the canyon. The treatment plant and the several recreational lakes will ultimately be located between these proposed facilities.

TREATMENT FACILITIES

The Santee County Water District is a public agency that provides water for the 12,000 people living within its district and, in addition, operates a sewerage facility for the same area. Tributary sewage flow has currently averaged 0.9 million gallons per day (mgd). The sewage is treated in an activated-sludge-type sewage treatment plant with a design capacity of 2 mgd. The entire sewage treatment and water reclamation process consists of the following units:

Unit	Design capacity, mgd
Raw sewage lift station — comminuter, bar screen, 2 pumps: No. 1, 2,200 gpm; No. 2, 2,800 gpm	4
Primary clarifier, 45 ft i.d., 95,000 gal vol	2
Sludge digester, 45 ft i.d., 50,000 ft^3 vol	2
Activated sludge, 67 ft i.d., 380,000 gal vol, 3 blowers 245 cfm each, 1 mixer and surface aerator with 60 hp motor	2
Oxidation pond, 16.0 acres, 30-million-gallon volume, Elev. 323 ft at water surface	
Transfer pump 1,160 gpm - 60 hp — 41 psi	
Transfer line 12 in. A.C. - 7,700 ft	
Spreading area-elev 395 ft, 6 basins 100 by 200 ft area = 3 acres	

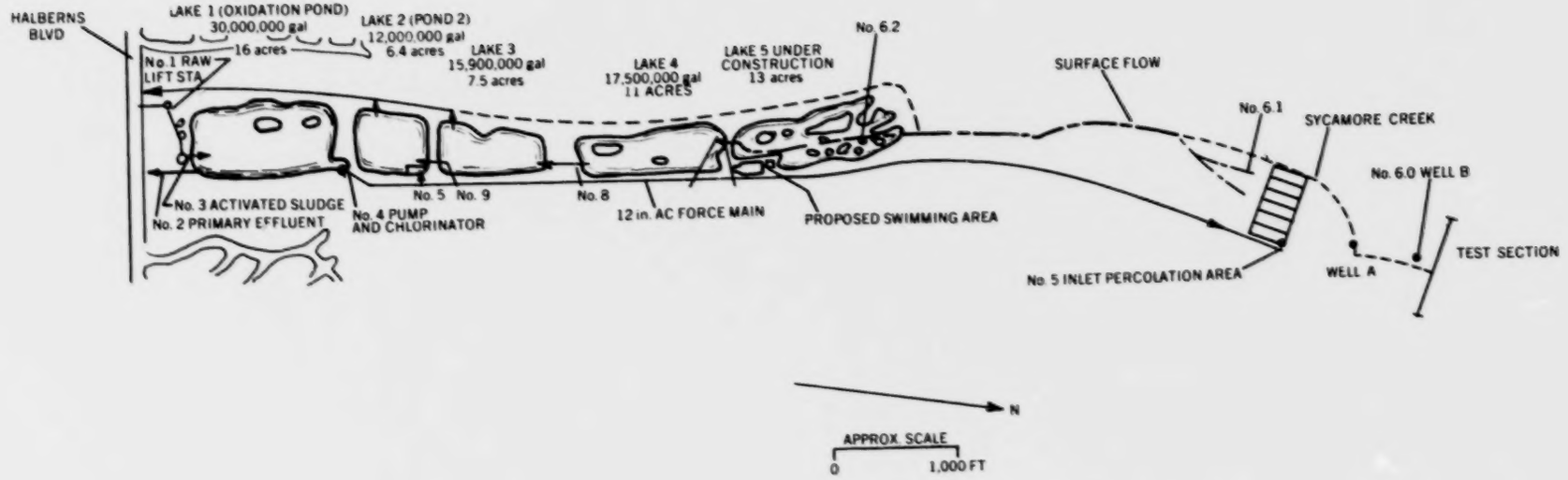

Figure 1. Location map Santee Recreation Project (numbers refer to sample locations).

Flow measurements are made by hour meters on the pumps and the operator's log. Flows into and out of Lake 4 are measured by rectangular weirs. The plant is usually operated with a return flow from the Oxidation Pond of about 0.2 mgd for addition of dissolved oxygen and for odor control. This flow returns to the main trunk sewer ahead of the lift station. Waste activated sludge is also returned to this sewer. Return flow is monitored by measuring the depth over the V-notch or rectangular weir. Supernatant flow from the digester can be returned to the primary unit or diverted to the Oxidation Pond as it was during the August through November 1962 period. A small flow of air (about 50 cfm) has been directed into the Oxidation Pond near the supernatant discharge point since November 1962.

The activated-sludge unit is a combination aeration and solids contact unit (aero-accelator) in which the aeration chamber contains about 12 percent of the total volume of 380,000 gallons. One or two blowers of 245 cubic feet per minute (cfm) each and mechanical mixer have provided treatment for 0.9 mgd. Suspended solids in the mixed liquor are usually kept at about 6,000 milligrams per liter to control foaming. Flow from the activated-sludge process enters the 30-million-gallon-capacity Oxidation Pond at about a 10-foot depth near the south end. Flow from the Oxidation Pond can be chlorinated prior to pumping to either Pond 2 or to the spreading area 8,500 feet north. Chlorination was required for all flow from Pond 1 until April 1963, but only for flow pumped to Pond 2 after April 1963. Contact time at the pumping rate of 1,160 gpm is 35 minutes to the spreading area and about the same in the detention chamber in Pond 2. The spreading area consists of six basins of about 1/2 acre each. These basins are fed by a cross-trench that was originally one of a series of eight trenches in which spreading was done. Considerable difficulty has been experienced with the spreading area because of the volume of flow, low permeability, and limited hydraulic grade available. During the first year, all flow was pumped to the basins for 1 or 2 days and then shut off for as long a period as possible to allow the beds to dry. During the second and third years, flow was pumped to the basins for 1 day of each 3 or 4.

Flow from the infiltration area first surfaces in a shallow ditch about 200 feet below the spreading area. The volume of surface flow developed in this stream represents flow in excess of the aquifer's transmissibility. Flood flows are diverted around the spreading area but return and mix with the recovered waste-water flow in the stream flowing to Lake 4. All the flow developed in the stream was originally accumulated at a collection gallery, which also recovered most of the ground water flow in the valley. This collection gallery has been continually moved upstream ahead of the gravel excavation. A transfer pipe through the dike at the upper end of Lake 4 allows flows up to about 3 mgd to enter the lake. Flows above this quantity enter the flood control channel west of the recreational lakes. The flow pattern is through Lake 4 to Lake 3 and then either to Lake 2 (Pond 2) or to the flood channel.

RECREATIONAL FACILITIES

The upper two lakes, 3 and 4, which were graded from the gravel operations, have been developed with grassed areas and other planting. Islands have been left in Lake 4, and picnic tables, playground facilities, and a dance platform are provided. Figure 1 illustrates the location of the lakes and their size and volume. Lake 5 is being constructed north of Lake 4 and is planned to provide a swimming area and several islands.

The recreational season at the Santee Lakes is primarily from May through December, but the lakes are open Saturday, Sunday, and Holidays from about noon until dark during most of the year. Recreational use of the Santee Lakes is limited to boating in sail or rowboats and fishing. Until April 1964 the fishing program required the return of all fish caught. Since then there has been a catch limit. Use of the grassed areas adjacent to the lakes is primarily for picnicking, but some playground facilities are provided. Special group use for scouting or artist activity is occasionally permitted.

STUDY PROGRAM

The first of a series of 2-week sampling periods was started in February 1962. The most recent of the eight quarterly sampling periods was completed in January 1964. This background study produced information regarding hydrology and flow; analyses for bacterial indicators, coliform, fecal coliform and fecal streptococci; the usual sewage quality parameters; and rather detailed chemical analyses of all waters in the study area. Sampling frequency varied from once each 4 hours for some of the bacterial samples to once per quarter for some of the chemical analyses. Some proportional samples were obtained from the plant inlet and the primary and secondary effluents.

Sampling locations include the following as shown in Figure 1:

1. Raw sewage at plant inlet
2. Primary settled effluent (in overflow channel)
3. Activated-sludge effluent (in overflow channel)
4. Oxidation Pond effluent (surface of pond at pump)
5. Oxidation Pond effluent chlorinated (at spreading basin)

5 A. Oxidation Pond effluent chlorinated (at Inlet Pond 2)

5 B. Outlet Pond 2

6. 0. Ground water (Well B) above spreading basin

6. 1. Ground water at start of stream 200 feet south of spreading basin

6. 2. Ground water in collection ditch 2, 500 feet south of spreading basin

7. Inlet water at Lake 4 (collection gallery)

7 A. Inlet water chlorinated at Lake 4

8. Outlet water at Lake 4

9. Outlet water at Lake 3

Additional ground water samples were occasionally obtained from small wells dug into the aquifer between locations 6.1 and 6.2.

The virus study, started in July 1962 by the San Diego County Department of Public Health with assistance from the California State Water Quality Control Board and the U. S. Public Health Service, provided analyses from weekly samples obtained from seven locations at Santee during the first year and at fewer locations on alternate weeks during the second year. Virus samples have generally been obtained by the swab technique with immersion times of 48 to 72 hours, and each sample had a correlating bacterial grab sample. During each sampling period, dissolved oxygen and phytoplankton determinations were made, and since September 1962, a more complete biological study has been incorporated in the study. A regular vector control study involving sampling once or twice per month was carried out by the California Department of Public Health. The two recreational lakes were planted with several species of fish, and continuing sampling has been done by the California Department of Fish and Game to monitor growth and development.

During the second year, an epidemiological study was made with a sample group of residences in the adjacent area. Illness records were obtained to correlate with use of the recreational lakes as determined by registration at the lake entrance.

PRESENTATION OF DATA

The following summaries are based on data supplied by the cooperating agencies. Summaries or abstracts of data supplied have been made at the discretion of the authors.

Flow and Hydrology

A summary of flows in the treatment system and recreational lake is shown in Table 1 for all sampling periods. These flows were obtained by daily readings of pump hours and weirs or, where applicable, readings at a 4-hour frequency. This summary shows that the 1962 annual average net plant inflow was 0.9 mgd based on estimated recirculation rates of 0.2 mgd. During the test period, active services increased by 8 percent to 3,080 by the end of 1963. The estimated flow in 1963 was 0.95 mgd based on a recirculation rate of 0.16 mgd. All pumps were calibrated by use of a Parshall flume, and the weir measurements were based on a standard coefficient. Oxidation Pond losses

are shown to be 180,000 gpd for 1962 and only 130,000 gpd for 1963. Since a normal 5-foot evaporation rate can account for only 70,000 gpd on the 16-acre pond, the balance of the loss can be accounted for by irrigation of plant grounds (30,000 gpd) and by percolation. Flows pumped to the percolation area for collection and supply to the recreational lakes are shown in Table 2 for both 1962 and 1963. Also shown on this table are estimated ground and surface flows for the canyon above the spreading area. These ground water flows were determined from elevations of test Well B (Station 6.0), and a bedrock cross section of the valley above the spreading area. At this cross section, five test holes were dug to the impermeable bottom formation so that an elevation-discharge relationship could be developed. A sixth test hole, Well A, 500 feet below the cross section, and an old well 500 feet upstream were used to develop ground water slopes. Two measurements of flow to determine underflow were taken by the California Department of Water Resources. Their report states (based on a permeability value of 1,000 gpd/ft^2 at a unit hydraulic slope), "...the natural underflow through Sycamore Canyon during the early part of February, 1962 is estimated to have been a maximum of 15 gallons per minute or approximately 22,000 gallons per day...". A second determination, with the same permeability, was made on March 22, 1962, when there was surface flow. Underflow at this time was estimated at 100,000 gpd. With a permeability value of 1,500 gpd per square foot at a 100 percent slope, ground water flow would equal 150,000 gpd when there is surface flow.

At the normal low-water elevation of 394 feet in Well B, a wetted cross section area of about 1,400 square feet provides an estimated discharge of 14,000 gpd at a 1 percent slope and permeability of 1,000 gpd per square foot as suggested by the report of the Department of Water Resources. Table 2 indicates that during 1962 the average flow infiltrated was 0.72 mgd. An estimated average ground water flow of 0.04 mgd was also developed. At this flow the dilution effects of the ground water would be about 6 percent. With less infiltrated flow and less rainfall, dilution was about 3 percent in 1963.

Percolated waste-water flows reach the surface in small volume in two streams about 200 feet below the downstream edge of the percolation trenches. After the trenches were replaced with six 1/2-acre beds in March 1962, percolation was accomplished more effectively until clogging increased. Then the streams were deepened to increase the slope and remove larger quantities of infiltrated water. During November, increased hydraulic gradients of about 4 percent slope from the beds to the stream were apparently causing more than half of the flow to reach the surface stream within 500 feet of the percolation area. Residence time for the full flow under ground at this distance is about 1 day for sample point 6.1, and at least 90 days for the residual flow reaching the surface at sample point 6.2. Percolation rates for the 0.72 mgd on 3 acres equals about 0.75 foot per day, and the saturated zone reaches to the surface of most beds. Because of continual problems with infiltration, reduction in volume of infiltrated flow was made after the first year. During the changeover in operating condi-

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Table 1. FLOW SUMMARY, mgd

Test period (2 weeks)	Plant inlet	Recir flow	Net flow	Pond 1 effluent to		Lake 4	
				Pond 2	Perc area	Inlet	Outlet
Feb 196[illegible]	1.17	0.19	0.99	0	0.98	1.00[a]	0.80
May	0.99	0.07	0.92	0	0.63	0.95[a]	0.75
Aug	1.07	0.15	0.92	0	0.76	0.59	0.42
Nov	1.03	0.20	0.83	0	0.68	0.61	0.42
Average 1962. .	1.10	c	0.90[b]	0	0.72	0.70[b]	0.50[b]
April 1963. .	1.03	0.16	0.87	0.53	0.17	0.17	0.03
July	1.18	0.18	1.00	0.34	0.49	0.27	0.09
Oct	1.06	0.14	0.92	0.31	0.65	0.35	0.20
Jan 1964. .	1.11	0.17	0.94	0.45	0.46	0.28	0.16
Average 1963. .	1.11	c	0.95[b]	0.42	0.40	0.34	0.20[b]
Average 1964. .	0.90	0	0.90	0.52	0.27	0.29	0.15[b]

[a] Includes surface flow.

[b] Estimated.

[c] No record.

Table 2. RECREATION LAKE FLOW SUMMARY, mgd

	Pond 1 effluent to perc area		Natural flow (est) Sycamore Canyon				Recreation Lake 4 inlet	
			Surface		Ground			
	1962	1963	1962	1963	1962	1963	1962	1963
Jan	0.67	0.74	0.	0	0.02	0.01	a	0.60
Feb	0.78	0.69	0.5	0	0.04	0.02	1.00[b]	0.55
Mar	0.61	0.27	0.2	0	0.10	0.02	a	0.40
Apr	0.78	0.28	0.1	0	0.06	0.01	a	0.17
May	0.63	0.29	0	0	0.04	0.01	0.95[b]	0.27
June	0.70	0.27	0	0	0.03	0.01	0.65	0.27
July	0.76	0.34	0	0	0.02	0.01	0.63	0.25
Aug	0.76	0.25	0	0	0.02	0.01	0.59	0.20
Sept	0.71	0.35	0	0	0.02	0.01	0.60	0.25
Oct	0.87	0.54	0	0	0.01	0.02	0.61	0.40
Nov	0.68	0.53	0	0	0.01	0.02	0.61	0.40
Dec	0.74	0.27	0	0	0.01	0.01	0.62	0.34
Average	0.72	0.40	0.07	0	0.04	0.01	0.70[c]	0.34

[a] No record.

[b] Includes surface flow.

[c] Estimated.

tions in March 1963, ground water flow was found to equal about 0.15 mgd when the stream was dry for its full length of 2,500 feet to the cutoff trench at sample point 6.2. This flow would verify the higher permeability of 1,500 gpd per square foot at a unit hydraulic slope. From this point, which is at the upper end of proposed Lake 5, all flow is in the surface stream. During the balance of 1963, infiltrated flow has averaged 0.40 mgd and recovered flow has averaged 0.34 mgd. At this flow, the upper end of the surface stream is intermittent as a result of periodic spreading.

Soil samples obtained from four locations showed effective sizes of 0.17 to 0.37 millimeter and uniformity coefficients of 2.5 to 5.5. The spreading basins reflect this variation in their unequal rates of drying. The slowest drying basin requires about 4 days to dry, whereas the fastest required only about 1 day.

Table 2 also shows that losses in recovered ground water flow were in excess of 0.1 mgd in 1962 but only 0.07 mgd in 1963. This loss was primarily due to evapo-transpiration, and the reduction was in part due to the placement of a cutoff trench to reduce flow around the west dike of Lake 4.

Weather

The weather at Santee is typical of south coastal California. Rainfall is less than 15 inches per year and evaporation equals about 65 inches in the near coastal area. The weather record at the nearby Gillespie Field airport is shown in Table 3 for both years of record. Rainfall was below normal during both years. Surface flows were, however, developed during 1962, after rains had filled the aquifer. The surface flows reached a peak of about 4 cfs and were maintained until April 1. During 1963, surface flow was minor and ground water elevations varied only by 1 foot above the percolation area. Most days during the year are sunny with occasional early morning low clouds that disappear by noon. Winds are generally westerly and blow most vigorously during the afternoon. These winds are capable of causing waves on the surfaces of Lakes 3 and 4, but usually do not affect the Oxidation Pond. Since the winds blow across the lakes, they are a beneficial factor in the sailboat activity. Air temperatures exceed 100°F and go below freezing in the winter. The extreme weather changes cause fall turnover of the lake and pond waters. Average air temperatures did not vary more than 1°F from normal during the test period.

Water Quality

PHYSICAL AND CHEMICAL QUALITY

A summary of average 11:00 am water temperatures recorded during the eight sampling periods is shown in Table 4. Minimum

Table 3. PRECIPITATION AND TEMPERATURE AT GILLESPIE FIELD

(2 miles southeast of Santee)

	Precipitation, in.			Air temperature, °F					
				Maximum			Minimum		
	1962	1963	1964	1962	1963	1964	1962	1963	1964
Jan	3.45	0.72	1.49	84	82	88	23	22	24
Feb	4.07	1.98	0.81	76	96	81	31	38	27
March	1.17	1.79	2.15	78	82	85	30	33	31
April	T	1.24	0.64	93	83	96	43	36	38
May	0.81	0.09	0.69	88	87	87	45	42	43
June	0.03	0.13	0.01	93	90	93	49	47	44
July	T	0.00	T	94	94	98	52	48	51
Aug	0.00	0.01	T	98	95	97	56	52	53
Sept	0.00	2.40	T	100	111	99	52	55	47
Oct	0.01	0.34	0.12	97	89	103	44	46	41
Nov	0.01	1.98	1.59	90	88	92	33	33	28
Dec	0.36	0.12	1.15	82	87	80	26	26	22
TOTAL	9.91	10.80	8.65	100	111	103	23	22	22

Temperature range	Maximum	Minimum
1951 – 1963	111	19

Annual precipitation	Average
1929 – 1959	13.8

Table 4. WATER TEMPERATURE SUMMARY (average °F, 11am)

Sampling period	Location					
	3	4	5	6.0	7	8
Feb 1962	68	a	61	63	60	60
May	74	72	72	67	75	74
Aug	82	83	81	a	80	79
Nov	74	67	65	a	68	64
April 1963	70	73	70	67	69	68
July	79	82	78	75	79	79
Oct	78	72	72	74	73	70
Jan 1964	66	55	53	63	55	50

[a] No record.

temperatures were reached in January 1964, with air temperatures equal to lows of record. Maximum variations occurred for locations 4 and 8, with a difference of about 30°F. Variations in the Recreational Lake 4 inlet was 25° and 18°F in the activated-sludge effluent. Ground water showed a variation of 12°F; it is likely that the shallow well casing increased ground temperatures during low-flow conditions.

The temperature record of the raw sewage for each of the four sampling periods in 1962 has been summarized to show the range and average for each 4-hour interval and is depicted in Figure 2. Maximum average variation was from 67° to 84°F, but individual readings ranged from 65° to 84°F. The averages for each of the test periods showed that the daily minimum occurred at 7:00 am, with the maximum most

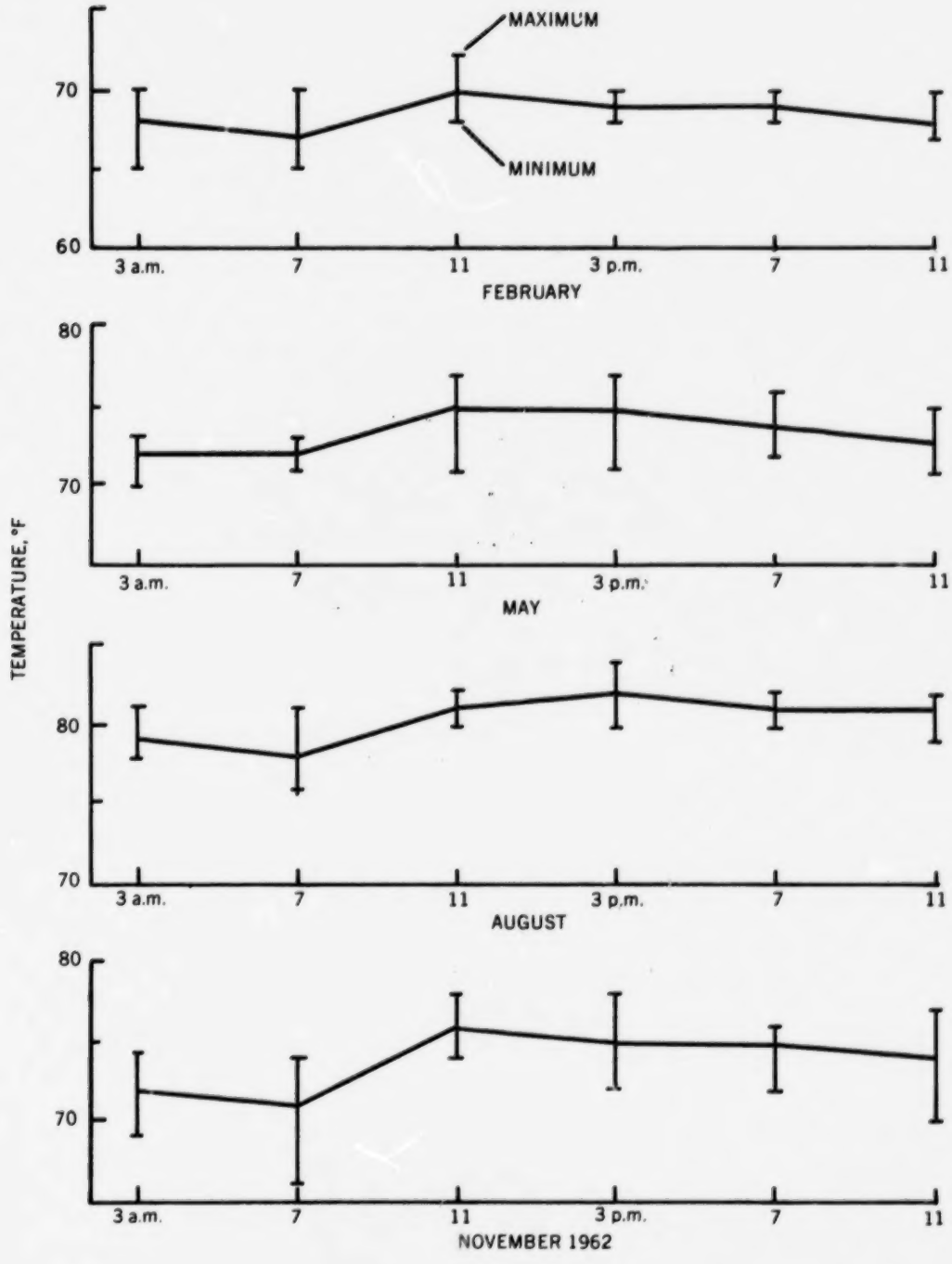

Figure 2. Range and average raw sewage temperatures.

often at 11:00 am. Figure 3 shows the average diurnal temperatures for four sampling points throughout the project for the 2-week sampling periods during May, August, and November 1962. Maximum temperature ranges of 15°F are shown for May and 17°F for August. The maximum water temperature in the Oxidation Pond, 90°F, occurred in August. Minimum water temperatures in Lake 4 and the Oxidation Pond were 60°F in November, but dropped to 50°F later in the year.

Measurement of dissolved oxygen and temperature were made at several locations on all the lakes. These measurements are summarized in Table 5. Maximum variation occurred in the Oxidation Pond where daytime dissolved-oxygen concentrations in excess of 20 milligrams per liter were usually found at some surface locations. During the August 1962 sampling period, both thermal and dissolved oxygen stratification occurred continuously in the Oxidation Pond. No dissolved oxygen was found below the thermocline. This condition again existed in July 1963. During spring very little stratification was noted in any of the lakes. In November 1962, a relatively great temperature difference was again found in the Oxidation Pond, but it could disappear with a turnover caused by wind or temperature drop. The effect of wind mixing was greater in the recreational lakes than in the Oxidation Pond. It is also obvious from the dissolved oxygen records that the greater oxygen demand of biological action in the Oxidation Pond can quickly depress oxygen to minimum concentrations while the water in each of the other lakes tends to hold dissolved oxygen at concentrations suitable for fish propagation.

During 1963 when Lake 2 was operated as a second pond receiving chlorinated effluent from Pond 1, the dissolved oxygen in this pond was usually depressed during and immediately following flow periods. New algae blooms usually brought about a quick recovery when flow ceased. These sudden changes could adversely affect the quality of water discharged from this operation.

The record of dissolved oxygen for the lakes shows that Lake 4 maintained highest levels and Lakes 3 and 2 progressively lower levels with minimum readings of 1 ppm in both Lakes 3 and 2. The photosynthetic production of oxygen was always apparent in Lake 4, but sometimes lacking in Lakes 3 and 2. Diurnal variation of dissolved oxygen shows average increases from levels of 13.4 to 21.2 milligrams per liter between 7:00 am and 11:00 am for Lake 4. Dissolved oxygen levels are shown in Figure 4 for several surface locations for water flowing through Lakes 4, 3, and 2 on three separate days during 1962. The variations in biological activity in each of the lakes are apparent.

Suspended solids and volatile suspended solids measurements were made for all sample stations. Great variations were found in the raw and primary effluents. Some of these concentrations likely reflect the return of excess activated sludge to the incoming sewer. Others reflect the short-circuiting characteristics of the primary tank.

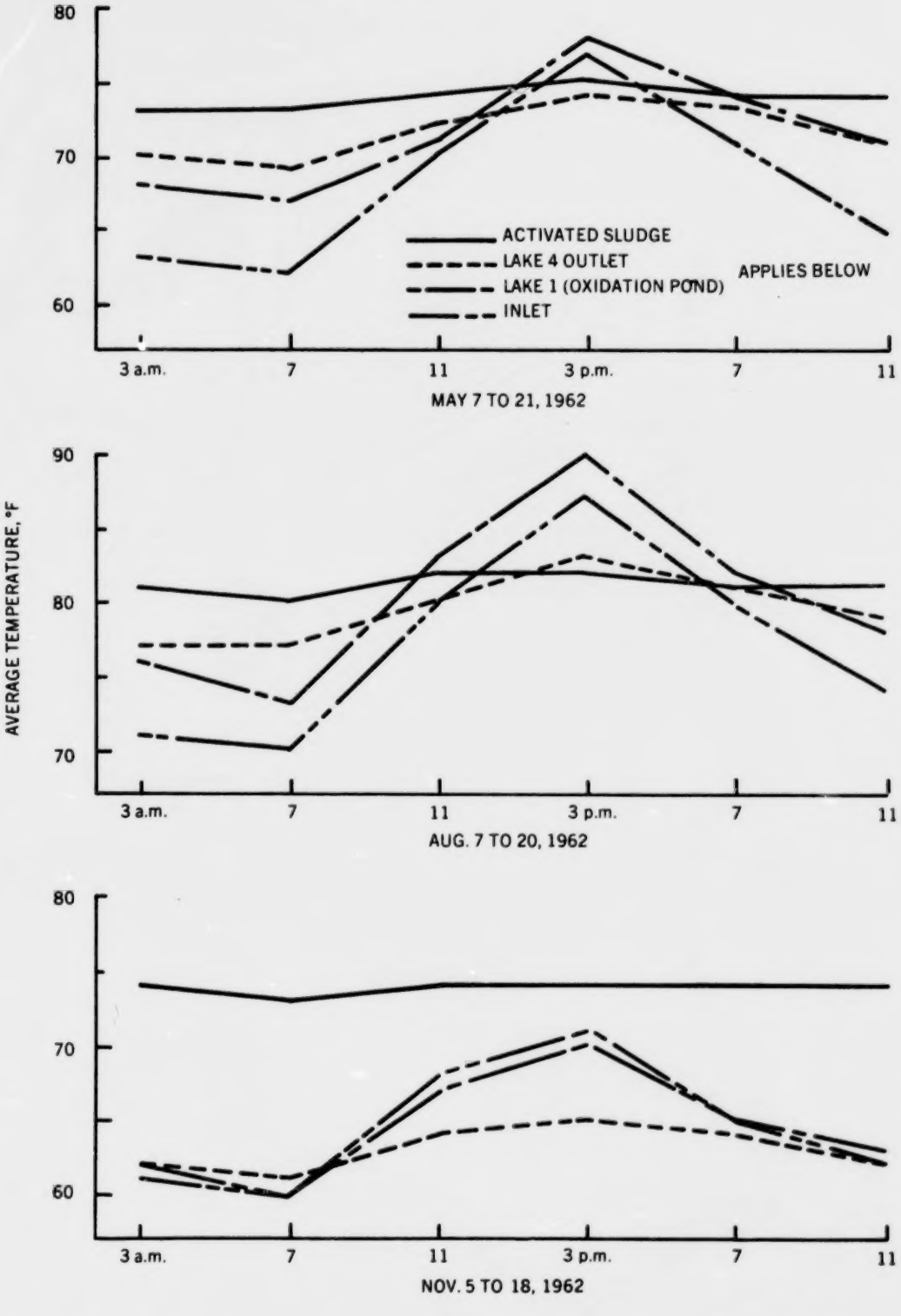

Figure 3. Diurnal temperatures for activated sludge, oxidation pond and Lake 4 inlet and outlet.

Table 5. DISSOLVED OXYGEN SUMMARY, (10 am to 3 pm)

Sampling period	Surface			At 4- to 5-ft depth		
	DO range, mg/liter	DO avg, mg/liter	Avg °F	DO range, mg/liter	DO avg, mg/liter	Avg °F
			Pond 1			
May 1962	9 to 26	15	66	9.0 to 21	13	65
Aug	14 to 38	23	84	0 to 0	0.0	78
Nov	7.4 to 45	22	68	4.6 to 26	12	65
April 1963	11 to 22	16	65	6.6 to 8.4	7.5	64
July	12 to 38	22	80	0 to 4.2	1.0	76
Oct	0.4 to 14	8.7	70	0.8 to 1.8	1.3	70
Jan 1964	13 to 22	19	56	9.2 to 14	12	52
			Pond 2			
April 1963	13 to 19	18	65	6.4 to 8.6	7.5	63
July	2.2 to 20	10	78	0.0 to 4.0	1.0	75
Oct	0 to 2.4	0.3	69	0 to 0	0.0	68
Jan 1964	7.2 to 15	12	53	6.0 to 100	7.0	52
			Lake 4			
May 1962	5.8 to 19	12	66	8.6 to 12	11	66
Aug	4.4 to 11	7.8	79	4.4 to 7.8	5.9	77
Nov	7 to 17	13	63	8.0 to 12	10	61
April 1963	8.0 to 14	11	64	7.0 to 9.0	8.0	64
July	8.0 to 14	11	76	7.2 to 11	8.9	75
Oct	7.2 to 10	8.7	69	8.2 to 10	9.1	68
Jan 1964	10 to 13	12	50	11 to 12	12	50
			Lake 3			
May 1962	3.4 to 10	6.7	67	4.6 to 9.4	6.8	66
Aug	8.0 to 15	11	81	6.8 to 8.0	9.8	78
Nov	7.0 to 10	9.2	64	7.0 to 8.8	7.4	62
April 1963	4.2 to 5.2	4.8	65	0.6 to 2.2	1.4	64
July	6.4 to 20	13	77	0.6 to 19	9.1	75
Oct	8.0 to 8.8	8.4	70	8.0	8.0	69
Jan 1964	12 to 15	13	51	11 to 14	13	51
			Lake 2 (Pond 2 in 1963-4)			
May 1962	4.0 to 8.4	6.7	66	4.4 to 7.4	6.1	66
Aug	9.0 to 18	13	82	6.8 to 8.0	7.4	78
Nov	0.8 to 3.6	1.8	63	1.0 to 1.2	1.0	62

Table 6 shows average operating levels of suspended solids and dissolved oxygen in the mixed liquor of the activated-sludge treatment. Suspended solids in the mixed liquor are usually kept at 6,000 milligrams per liter to control foaming. After November 1962, a cover was added to the aeration chamber to collect and recirculate foam to the plant inlet. This allowed operation at lower concentrations of suspended solids. One of the quarterly sampling periods was carried on with suspended solids concentrations of 3,600 milligrams per liter with no improvement in treatment noted. After a year's operation with no apparent benefit other than foam control, the cover was removed early in 1964. Occasional high readings of suspended solids in the secondary effluent are related to the carryover of activated sludge from the settling compartment. This characteristic was more easily controlled at the high solids level.

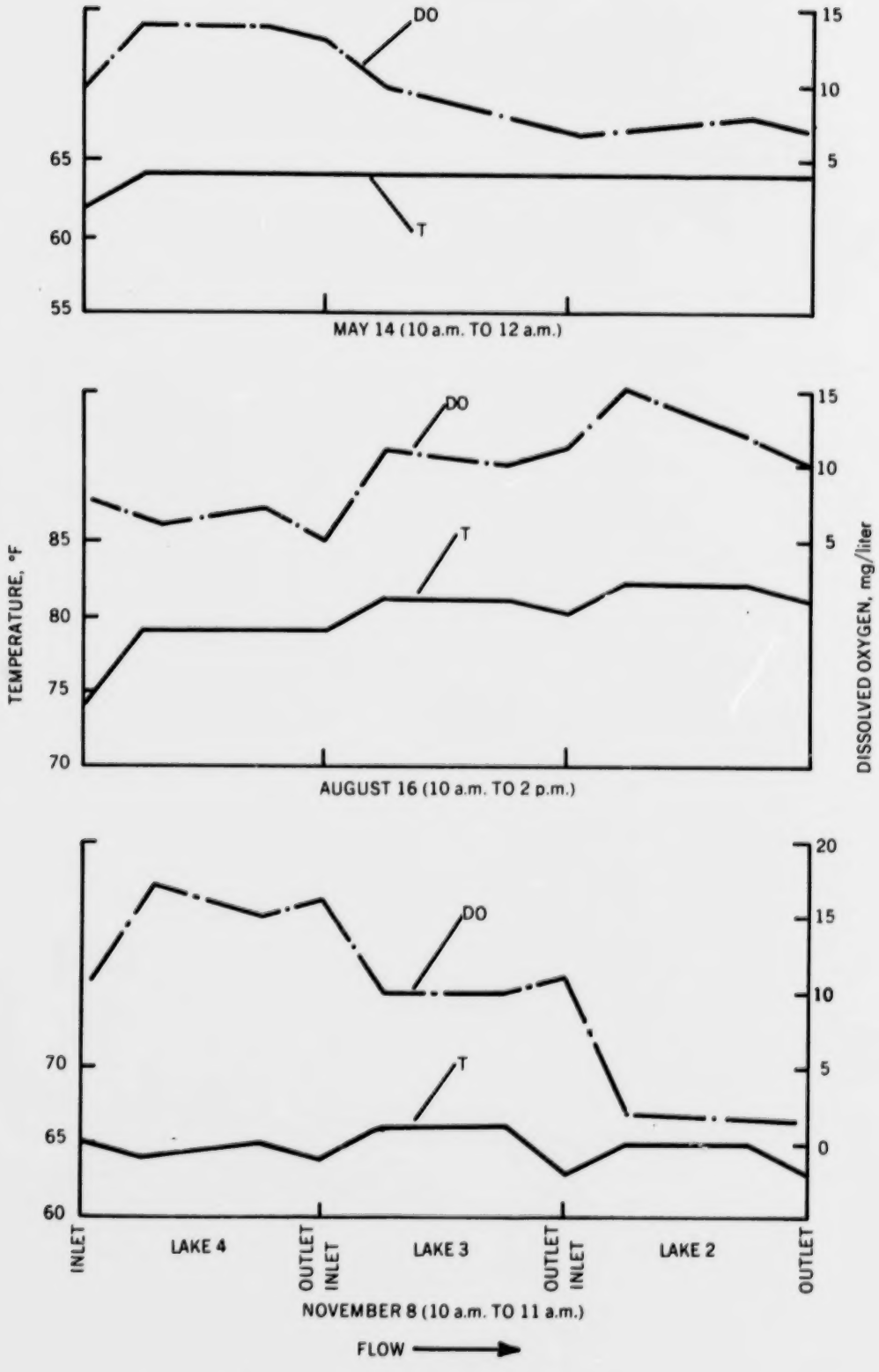

Figure 4. Dissolved-oxygen concentrations in Lakes 2, 3, and 4.

Table 6. QUALITY OF ACTIVATED-SLUDGE MIXED LIQUOR

Month	Susp solids, mg/liter	% Settleable	Sludge vol index	D.O., mg/liter
Feb 1962	6,140	84	137.	1.0
May	5,950	88	148.	1.2
Aug	7,330	97	132.	1.1
Nov	6,080	72	118.	0.9
Apr 1963	5,000	88	176.	2.5
July	3,680	35	95.	1.3
Oct	5,930	57	96.	0.6
Jan 1964	5,510	47	85.	1.0

Table 7. SUSPENDED SOLIDS, mg/liter

Location	Total		Volatile		Fixed avg
	Range	Avg	Range	Avg	
Plant inlet	120 to 1,970	580	105 to 1,849	501	79
Primary effluent	105 to 1,980	500	33 to 1,877	404	96
Secondary effluent	23 to 315	62	10 to 250	54	8
Pond effluent	17 to 173	69	17 to 129	55	14
Lake inlet	0 to 40	8.6	0 to 20	4.2	4.4
Lake outlet	1 to 29	13	1 to 15	8.3	4.7

Table 7 summarizes the range and average suspended (volatile and total) solids for each significant sample location for each sampling period. This chart shows that average removals of 89 percent were obtained in the conventional treatment plant, but were followed by a slight increase in the Oxidation Pond. This increase averaged less than 10 milligrams of primarily fixed solids per liter. After percolation, very small concentrations of both fixed and volatile suspended materials were found. In Lake 4, algal production increased volatile suspended solids by 4 milligrams per liter. Some variation in suspended-solids concentrations in the raw, primary, and activated sludge is caused by the return of 15 to 20 percent of the Oxidation Pond return flow to the plant inlet.

The nonvolatile suspended solids that have been pumped to the spreading basins are estimated to have equaled about 400 cubic feet through 1964. This material would fill a small percent of the voids in the top 6 inches of infiltration area surface soil and has likely added to the need for routine quarterly surface scarification. The paramount need for scarification is more likely caused by the clogging of the soil with digesting volatile material and larger volume of precipitated inorganic salts.

During the eight quarterly samplings, 5-day biochemical oxygen demand (BOD) measurements were made at each of four stages of the treatment process. These measurements are summarized in Table 8 to depict ranges and averages through the treatment process. Average BOD concentrations are shown to vary from about 300 milligrams per liter in the raw sewage to 3.5 milligrams per liter at the inlet to Lake 4. At the flow of 0.9 mgd the secondary treatment process showed a capability for removal of 88 percent of the BOD. Overall BOD removals through the percolation area were approximately 99 percent. Concentrations of BOD found in raw sewage were largest in February 1962. This was due to the operating difficulties with sludge pumping experienced in February. Five sets of composite samples on the raw, primary, and secondary effluent were also examined and these results showed removals of 85 percent for secondary treatment.

Table 8. FIVE-DAY BOD AND COD, mg/liter

Location	BOD		COD		Composite	
	Range	Avg	Range	Avg	BOD	COD
Plant inlet	134 to 630	301	256 to 1,930	1,090	268	1,020
Primary effluent	125 to 575	278	257 to 2,000	772	212	572
Secondary effluent	14 to 120	25	104 to 252	175	38	185
Pond effluent	16 to 60	29	55 to 328	185		
Ground water 6.0	1 to 8	1.5	0 to 77	24		
Ground water 6.1	1 to 9.1	4.4	29 to 60	46		
Ground water 6.2	1 to 6.4	2.1	0 to 32	19		
Lake 4 inlet	1 to 8	3.5	19 to 68	41		
Lake 4 outlet	3 to 10	6.0	24 to 112	52		

Of significance are the small BOD concentrations found at sample point 6.1, which is only 200 feet below the percolation area. The average 3.5 milligrams per liter measured at this point indicates very good removal in the percolation process. The BOD in waters at sample point 6.1 have not exceeded 10 milligrams per liter and are only double the concentrations found at sample point 6.2, which follows ground water travel of more than 2,000 feet. Normal removals seem to have been carried through the entire treatment process. The BOD of the inlet waters to Lake 4 would not be an indication of the water source.

Analyses for chemical oxygen demand (COD) were made at all eight original locations and also at intermediate points in the spreading area when significant changes were noted. Average COD results are shown in Table 8 along with ranges. As with BOD determinations, occasional high readings from the grab samples obtained from either the raw sewage or the primary effluent caused greater variations from the averages. Average concentrations at all other sampling points appeared to be consistent and showed overall removals of about 95 percent after percolation and 80 percent after secondary treatment. The Oxidation Pond waters showed a slight buildup from the average concentrations

found after activated-sludge treatment. This was especially true when supernatant was discharged directly to the pond. The percolation area provided an average removal of 75 percent of the COD carried in the Oxidation Pond effluent. The chlorination of the pond waters reduced the COD by 10 milligrams per liter. The two sample points, 6.1 and 6.3, showed COD concentrations that varied with time. Early in the study COD concentrations at 6.2 showed the dilution effects of rainfall. Later, as all the water in the underground basin became reclaimed water, COD concentrations at 6.1 and 6.2 became more nearly equal. The COD concentration in the final waters entering Lake 4 does represent one of the characteristics that could identify the source of the reclaimed water. Less than half of the final COD can be accounted for by BOD, nitrogen compounds, and ABS.

A conductivity record of plant influent and Lake 4 influent was obtained during February. In May an additional record of plant inlet conductivity was again obtained. These readings showed conductivity changes from an average of 1,500 micromhos to as high as 2,000 micromhos for an occasional period of 1 hour following softener backwash operations. Conductivity readings for the Lake 4 inlet were very consistent at levels of 1,300 micromhos and showed some change with the arrival of runoff in mid-February. Measurements of total dissolved solids by evaporation correlated well with conductivity and have been summarized in Table 9. The wide range in measurements for an individual sampling period was due to rainy periods. Variations among quarterly sampling periods for any individual station can be explained by entry of runoff or by concentration of salts through evaporation. Variations among sampling locations showed a slight decrease in the activated-sludge process and also a decrease in the percolation process. The reduction through the percolation process resulted from some dilution with natural ground water and some precipitation of calcium salts. This reduction decreased with time. The dissolved solids in the potable water averaged 750 milligrams per liter, and in the natural ground water at Station 6, dissolved solids ranged from 448 to 713 milligrams per liter.

Table 9. RANGE OF QUARTERLY AVERAGES (of total dissolved solids, pH, and alkalinity)

Location	TDS, mg/liter,		pH		Alkalinity, mg/liter	
	Range	Avg	Range	Avg	Range	Avg
Plant inlet	940 to 1,305	1,125	6.9 to 7.8	7.3	240 to 481	322
Primary effluent	970 to 1,255	1,124	6.1 to 7.9	7.3	252 to 404	353
Secondary effluent	1,030 to 1,160	1,080	6.6 to 7.9	7.3	268 to 368	314
Pond effluent	914 to 1,165	1,091	7.3 to 9.1	8.3	224 to 349	261
Ground 6.0	448 to 713	621	6.3 to 7.6	6.9	40 to 86	54
Ground 6.1	974 to 1,285	1,080	7.1 to 7.4	7.3	233 to 318	270
Ground 6.2	773 to 1,240	959	6.8 to 7.6	7.2	98 to 225	166
Lake 4 inlet	370 to 1,145	1,014	7.0 to 8.1	7.6	80 to 236	194
Lake 4 outlet	845 to 1,320	1,101	7.5 to 9.0	8.3	138 to 239	197

Measurements of alkalinity and pH have been graphed in Figure 5. Measurements in February were made in the field. All others were made in the laboratory. The Oxidation Pond and Lake 4 showed increased pH readings due to algae growths for all quarterly periods. Alkalinity removal occurred in both the pond and percolation process. Alkalinity removal in the pond was seasonally dependent on photosynthesis. The potable water delivered at Santee had a pH in the range of 7.5 to 8.5 and an alkalinity of about 120 milligrams per liter. Alkalinity of the natural ground water varied from 40 to 80 milligrams per liter.

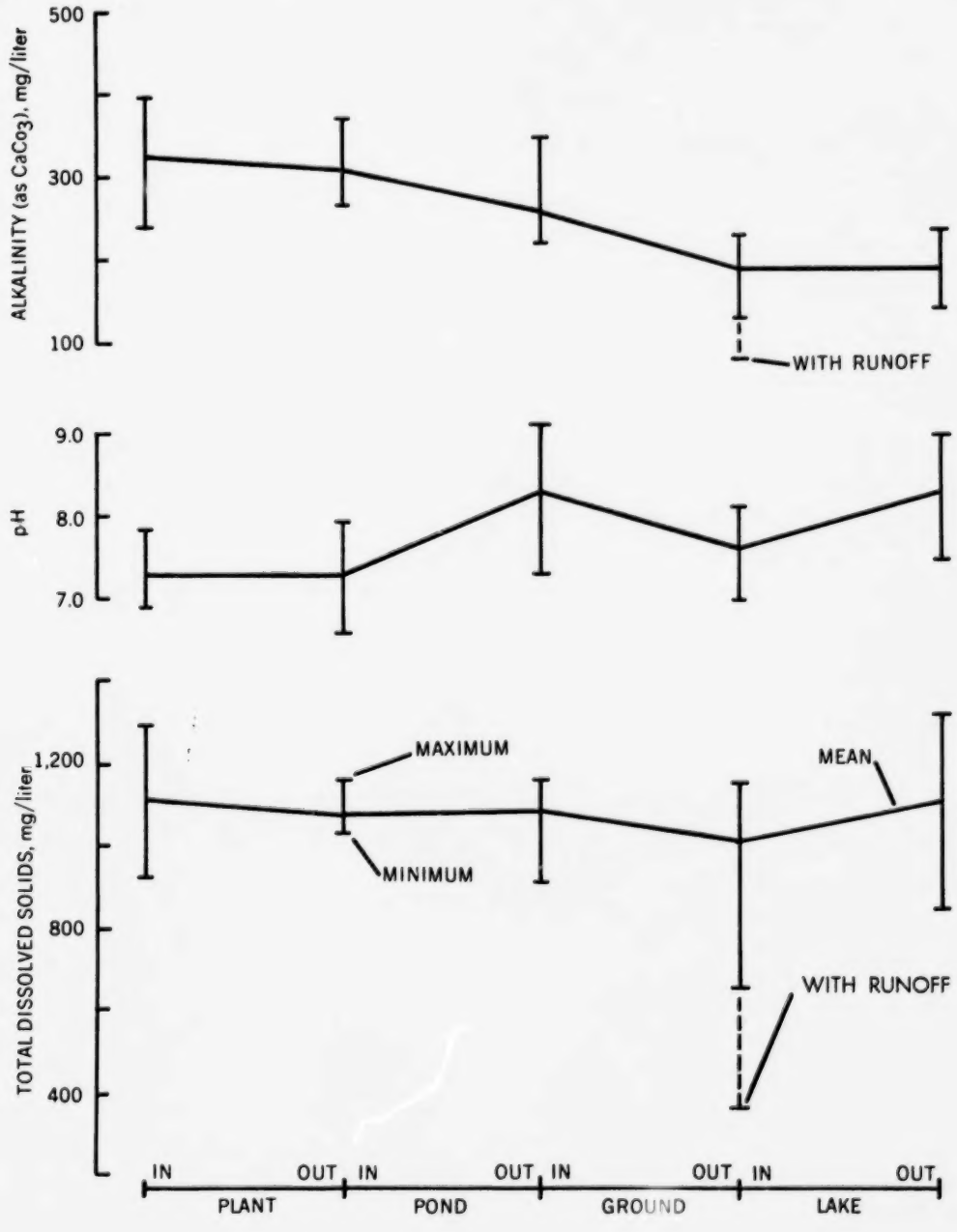

Figure 5. Alkalinity, pH, total dissolved solids range and mean.

Complete chemical analyses of waters at several stages in the reclamation process were obtained for each quarterly period. Composites were used for Stations 1, 2, and 3. Results of these analyses, except for boron, fluoride, and silica, have been plotted as milliequivalents per liter (meq/liter) in Figures 6 and 7. The loss of ammonia, potassium, and calcium through the process is apparent. Calcium is removed as calcium carbonate or phosphate in the Oxidation Pond, the lakes, and the percolation area. Figure 7 also shows reductions taking place for bicarbonate alkalinity and sulfate. Loss of alkalinity can be attributed to the above precipitation as calcium car-

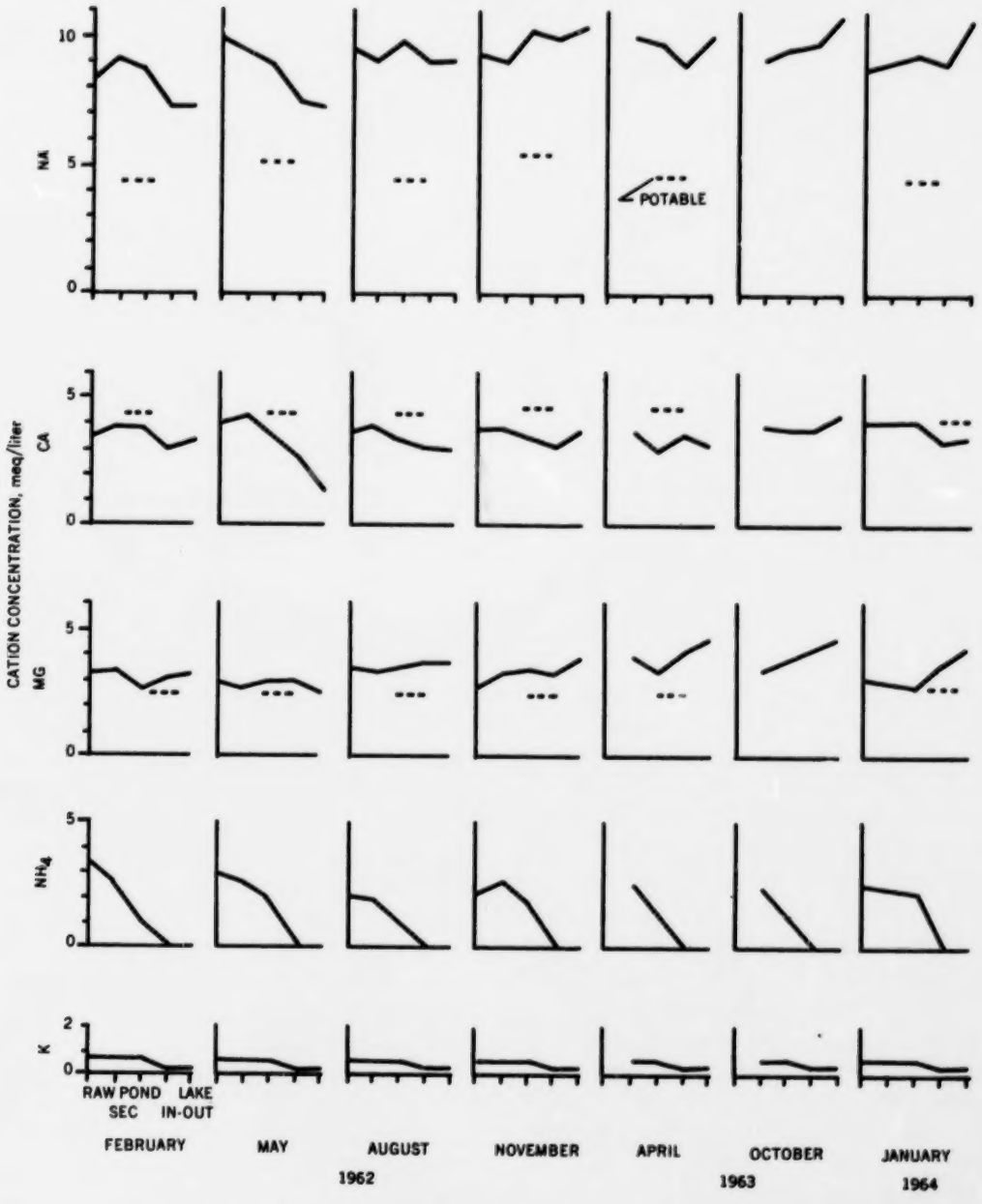

Figure 6. Quarterly range of Ca, K, Mg, NA, and NH_4 cation concentrations.

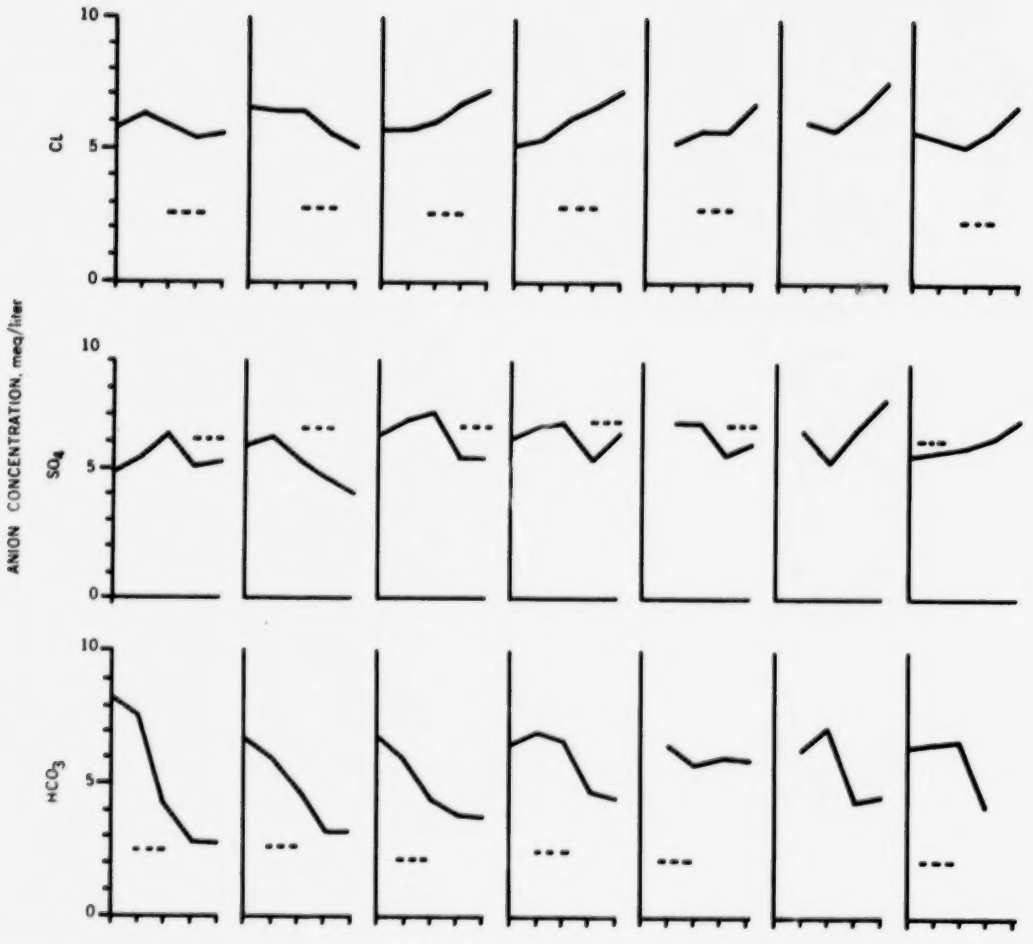

Figure 7. Quarterly range of Cl, HCO_3, and SO_4, anion concentrations.

bonate. The sulfate reduction in the percolation area appeared to end during the second year and was probably the result of ion exchange. The concentrating effects of the lakes resulting from evaporation were emphasized in August by changes in the sodium and chloride ions. The sodium and chloride ions showed similar stability at the various treatment stages except for a small loss of sodium after percolation that was apparent during the first year. This could be attributed to some ion exchange's taking place in the calcium-type soils. Results from Lake 4 inlet sampling point in November indicated that this soil capacity for exchange of sodium was exhausted. Potassium and ammonia are also shown in Figure 6, and their concentrations reached a minimum after the percolation process. The water in Well B had a sodium ratio of about 50 percent compared with sodium percentages of about 57 percent before and after percolation. The well water had a much smaller total ion concentration than the percolated waters did. As with the flow summary, ground water, from a chemical standpoint, can be credited with only a small effect on the percolating water, especially after extensive rainfall.

The measurements of fluoride and nitrate did not greatly affect ion balances since maximum concentrations were about 2 milligrams per liter for each. The fluoride concentrations in Lake 4 were at the potable-water concentration of 0.4 milligram per liter. Measurements of boron showed peak readings of about 1.0 milligram per liter and final readings of 0.6 to 0.8 milligram per liter in Lake 4. Silica concentrations varied between 16 and 30 milligrams per liter for all stages in the reclamation process with little change from the 19 to 28 milligrams per liter found in the raw sewage. The complete nitrogen cycle including nitrates, ammonia, and organic nitrogen is summarized in Table 10 and plotted by range of quarterly averages in Figure 8. Nitrite nitrogen was only significant at the entrance to Lake 4 where it was occasionally more than 0.1 milligram per liter. Effective treatment for removal of organic nitrogen has taken place in the activated-sludge and infiltration processes. The ammonia nitrogen conversion was accomplished in the pond, on the spreading ground, and in the stream. Analyses of water at location 6.1 showed a range of 0.32 to 14 milligrams of ammonia nitrogen per liter. The low readings at location 6.1 coincided with low flows to the spreading area in April 1963. The high reading for ammonia nitrogen at location 6.1 was always reduced by stream conditions so that Lake 4 inlet waters never exceeded 1.5 milligrams per liter. Nitrate nitrogen is built up in the spreading operation and occasionally to larger concentrations in the stream after the spreading operation. The water coming from the ground at location 6.1 also generally had a larger nitrate concentration than waters at location 6.2 did. Nitrate nitrogen was measured as high as 2.1 milligrams per liter at the entrance to the lake. Total nitrogen was reduced from an average of 60 to about 2 milligrams per liter at the inlet to the lake. Removal of nitrogen in the stream has been as high as 15 pounds per day.

A summary of the phosphate analyses is shown in Table 11, and a plot of averages for each sampling period is shown in Figure 9. Again

Table 10. SUMMARY OF QUARTERLY AVERAGE NITROGEN as N in mg/liter

	Organic		Ammonia		Nitrate[a]	
	Range	Avg	Range	Avg	Range	Avg
Plant inlet	17 to 42	26.8	29 to 36	32.4	0.10 to 0.27	0.18
Primary effluent . . .	16 to 71	32.6	37 to 43	41.3	0.09 to 0.21	0.16
Secondary effluent . .	4.8 to 36	11.6	21 to 34	29.4	0.05 to 0.36	0.14
Pond effluent	4.9 to 19	9.5	9.6 to 24	15.5	0.08 to 0.41	0.18
Ground water 6.0 . . .	0.33 to 3.4	1.33	0.0 to 0.7	0.19	0.08 to 1.5	0.41
Ground water 6.1 . . .	0.48 to 2.5	1.63	0.32 to 14	8.7	0.04 to 1.1	0.42
Ground water 6.2 . . .	0.21 to 1.3	0.74	0.0 to 0.9	0.39	0.06 to 0.6	0.23
Lake 4 inlet	0.22 to 2.4	1.39	0.03 to 1.1	0.76	0.03 to 1.1	0.49
Lake 4 outlet	0.73 to 2.0	1.49	0.0 to 0.17	0.25	0.03 to 0.17	0.094

[a] The only significant nitrite occurred in Lake 4 inlet where the range was 0.000 to 0.072 mg per liter and the average was 0.025 mg per liter.

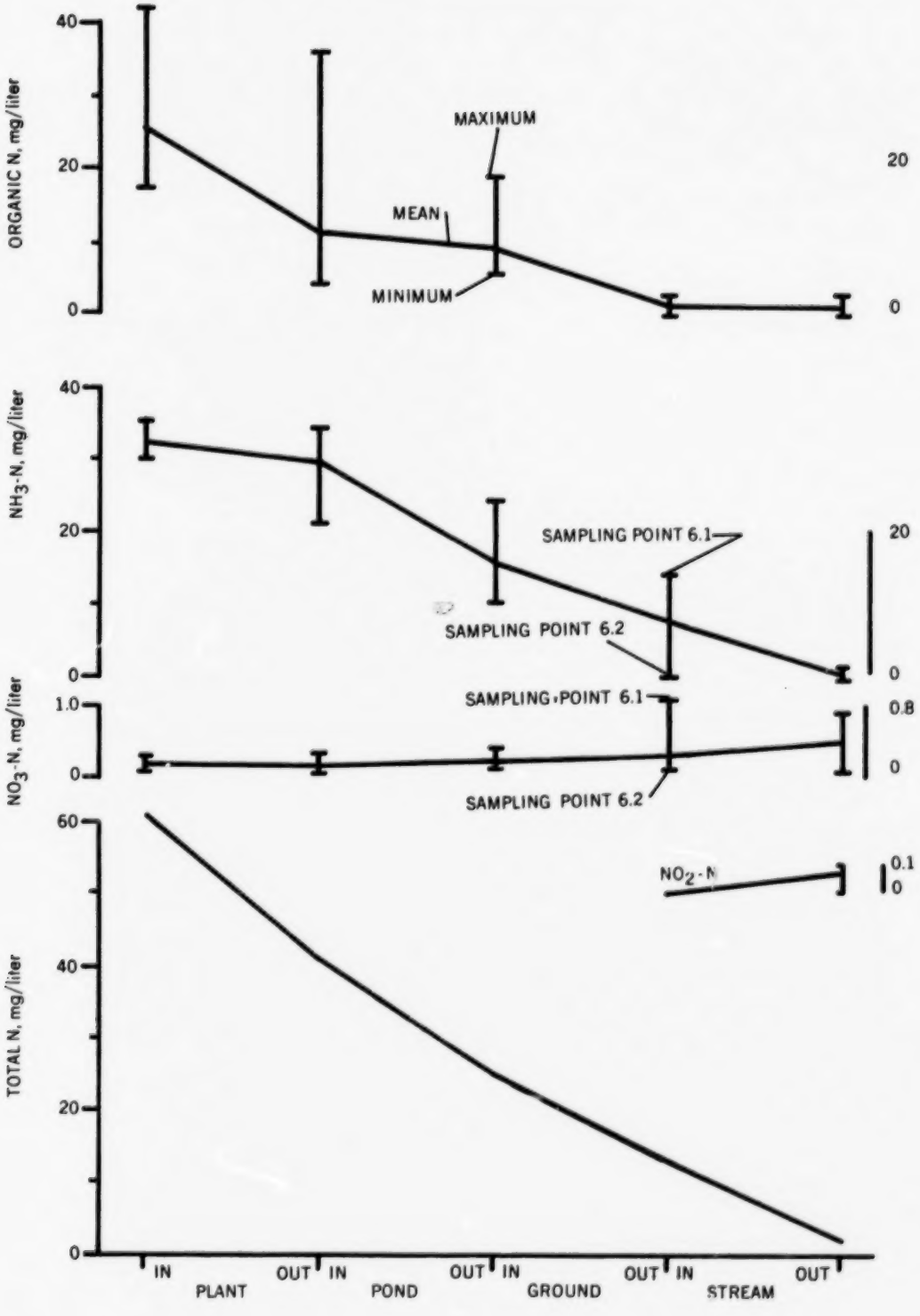

Figure 8. Summary of nitrogen averages range of quarterly values, mg/liter.

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Table 11. ORTHO AND TOTAL PHOSPHATES as PO_4 in mg/liter

Location	Ortho		Total [a]	
	Range	Avg	Range	Avg
Plant inlet	36 to 96	61		
Primary effluent . .	39 to 90	60		
Secondary effluent .	3.0 to 55	24	8.8 to 45	25
Pond effluent	11 to 41	24	19 to 41	30
Ground water 6.0 . .	0.0 to 4.2	0.5		
Ground water 6.1 . .	0.15 to 22	12		
Ground water 6.2 . .	0.0 to 1.3			
Lake 4 inlet	0.0 to 15	1.5	1.1 to 5.0	2.0
Lake 4 outlet	0.0 to 2.2	0.82	0.48 to 4.5	1.3
Lake 3 outlet	0.3 to 0.68	0.40 [a]		

[a] Record of two quarterly periods only (August and November 1962).

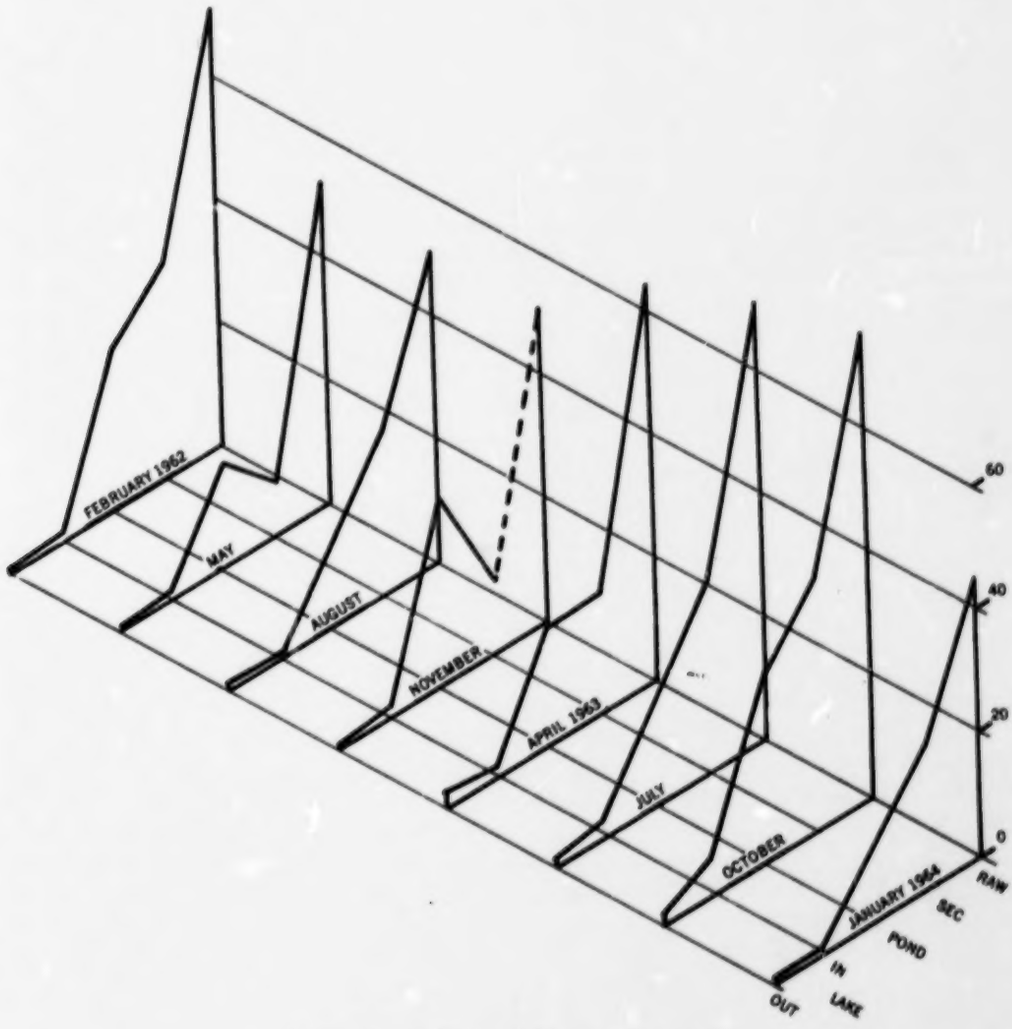

Figure 9. Orthophosphate as PO_4 in mg/liter.

it is significant that concentrations of phosphate reaching the inlet to Lake 4 showed average residuals of 1.5 milligrams of orthophosphate per liter in spite of concentrations of 10 to 12 milligrams per liter breaking through the infiltration area at sample location 6.1. The plot of average phosphate concentrations shows significantly smaller concentrations of phosphate at the pond inlet during the four quarters. The reduction in phosphate was greatest in the activated-sludge process, but great variability existed in the process. The average concentration of phosphate in the Oxidation Pond was 24 milligrams per liter, which equaled the average found in the activated-sludge effluent. Phosphates found in February 1962 in samples from the well above the infiltration area (sample station 6.0) declined after the rainfalls of 1962. Measurements of phosphate in both filtered and unfiltered samples were made in August and November 1962. These analyses showed that total phosphate equaled 125 percent of soluble phosphate for the activated-sludge and pond effluent samples. Total phosphate averaged 1.3 milligrams per liter for waters leaving Lake 4 and was 150 percent of the orthophosphate measurement.

The results of measurements of apparent ABS are tabulated in Table 12, and are plotted in Figure 10. Synthetic detergents have been controlled primarily by the activated-sludge process, which averaged about 50 percent removal. The pond and percolation processes have removed on the average an additional 30 percent. Apparently, the percolation process removed ABS by the adsorptive property of the soil early in 1962, since concentrations in samples obtained in November in the stream below the percolation area (location 6.1) gradually increased until the same concentrations were obtained as in the water being percolated. During the second year, after a period of no percolation, some improvement was noted. Waters obtained at sample location 6.1 showed concentrations that have gradually increased to about 30 percent of the ABS percolated. Some ABS destruction was probably occurring at the lower spreading rates. Soil adsorptive capacity was not reached for all of the basin prior to excavation by the materials company. Little change in ABS concentration has been apparent in Lake 4.

Measurements of phenol made at all stations during the February sampling period showed an average concentration of only 0.07 and 0.08

Table 12. APPARENT ABS in mg/liter

Location	Range	Avg
Plant inlet	6.8 to 27	16.5
Secondary effluent	4.8 to 11	8.5
Pond effluent	4.2 to 9.7	6.7
Ground water 6.0	0.0 to 0.63	0.2
Ground water 6.1	2.8 to 8.6	5.8
Ground water 6.2	0.9 to 2.4	1.7
Lake 4 inlet	1.5 to 5.2	2.9
Lake 4 outlet	1.4 to 5.0	3.0

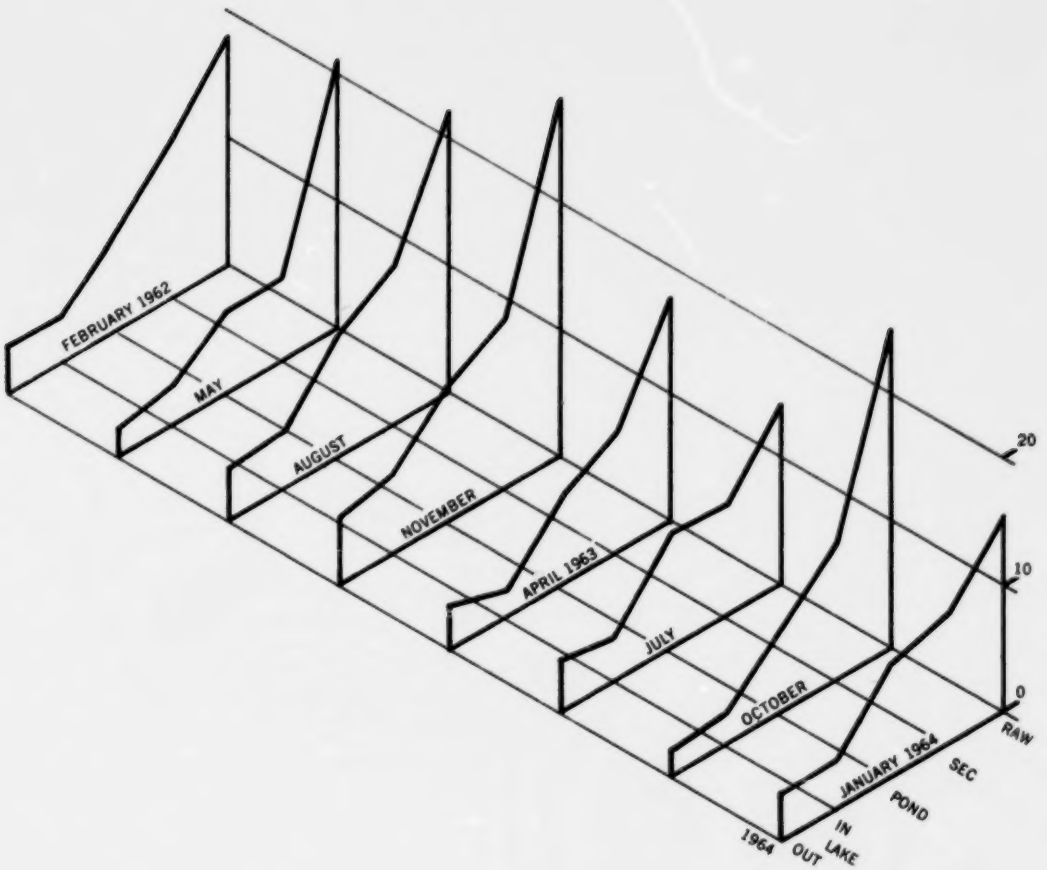

Figure 10. ABS in mg/liter.

milligram per liter in the raw and settled sewage and none at all other locations. It was thus concluded that the treatment process was completely effective in removing phenol.

Radiological analyses for both alpha and beta activity were made during February and August. In February significant beta activity was measured in the waters at the inlet to the percolation area. This activity of 419 ± 18.2 micromicrocuries per liter was most likely due to heavy runoff that occurred at this time. All other beta activity levels ranged from approximately 16 to 90 micromicrocuries per liter. Generally no significant alpha activity was found.

MICROBIOLOGICAL QUALITY

A record of the three bacterial indicators, coliform, fecal coliform, and fecal streptococci, as measured during the quarterly sampling periods, is summarized in Tables 13 and 14. A plot of the coliform and streptococci is shown in Figure 11. The coliform counts were originally obtained for each quarterly sampling period for samples collected at 4-hour intervals for 1 week at each sample location. Con-

firmations for fecal coliform were made by using incubation in E. C. Broth at 44.5°C and were limited to the incubator capacity in the mobile laboratory. After the February sampling, consolidation of the numbers and types of bacterial determinations were made, some stations averaged less than a dozen samples during the 2-week period. Frequency of fecal coliform determinations was varied to use the maximum capacity of the incubators available. Median MPN's for coliform and fecal coliform showed a diurnal variation for only the raw- and primary-effluent stations. The variation between early morning and later periods is apparent but negligible in light of low flows. The 11:00 am bacterial sampling time used in the virus study for comparative purposes by the San Diego County Department of Public Health is adequate when flows are considered. The County record is summarized in Table 15. Both median counts and the range from maximum to minimum are shown in this record. The median counts for both coliform and fecal coliform for each laboratory are in close correlation for the period of record. The median counts for fecal streptococci are less when obtained by M.F. procedures with K.F. agar than by the multiple-tube fermentation with standard methods.

Table 13. MEDIAN MPN SUMMARY FOR CONVENTIONAL TREATMENT SYSTEMS MPN/100 ml, COLIFORM, FECAL COLIFORM, FECAL STREPTOCOCCI IN MPN/100 ml

	1962					1963		1964
	Feb.	May	Aug.	Nov.	Apr.	July	Oct.	Jan.
Plant inlet								
Coli x 10^6	54	49	49	33	41	94	49	33
F. Coli, %[a]	39	25	27	40	47	20	57	20
F. Strep x 10^6	1.3	0.79	13	0.79	3.0	2.2	1.6	1.7
Primary effluent								
Coli x 10^6	54	79	64	49	33	56	49	41
F. Coli, %	26	26	28	55	50	39	67	23
F. Strep x 10^6	0.79	1.7	1.1	0.79	2.4	3.5	3.0	1.3
Secondary effluent								
Coli x 10^6	4.9	23	23	23	18	13	7.9	4.9
F. Coli, %	52	41	40	51	40	38	62	67
F. Strep x 10^6	0.13	0.79	0.46	0.79	0.64	0.49	0.49	0.33
Pond effluent (B.Cl.)								
Coli x 10^3	310	780	180	790	330	68	490	330
F. Coli, %	21	.....	.....	37	21	.....	29	40
F. Strep x 10^3	0.79	7.0	1.3	9.2	1.3	0.17	10.2	11
Pond effluent (A.Cl.)								
Coli	<2	4.5	39	4.5	4.5	127	180	2
F. Coli	<2	<2	<2	<2	<2	2	180	<2
F. Strep	<2	<2	<2	<2	<2	<2	2	<2

[a] Percent Fecal Coli was obtained from actual counts in 1962 and from ratio of Median counts in 1963.

Table 13 also shows the percent of fecal coliforms. Fecal coliform percentages were calculated for only those samples on which counts were made during the first year because of relatively few tests. During the second year, fecal coliform percentages were calculated from median counts. One significant change in these percentages is the increase in percent of fecal coliforms in the secondary effluent where fecal coliform ratios average more than 40 percent. The ratio of fecal coliforms decreases through the pond and after treatments.

The bacterial record of waters entering the infiltration beds and Lake 4 is summarized in Table 16 for both laboratories and for both operating conditions. This record shows that the prechlorination of percolated waters did not greatly affect the bacterial quality of water entering Lake 4. The bacterial content of the recovered ground water at location 6.2, after travel of 2,500 feet underground, was generally

Table 14. MEDIAN MPN SUMMARY FOR TERTIARY TREATMENT AND RECREATIONAL WATERS – COLIFORM, FECAL COLIFORM, FECAL STREPTOCOCCI IN MPN/100 ml

	1962					1963		1964
	Feb.	May	Aug.	Nov.	April	July	Oct.	Jan.
Waste water before infiltration								
Coli....	<2	4.5	39	4.5	4.5	68,000	490,000	330,000
F. Coli..	<2	<2	<2	<2	<2	18,000	140,000	130,000
F. Strep.	<2	<2	<2	<2	<2	170	10,200	11,000
Ground water 6.1[a]								
Coli.....	.....		35,000	8,000	.....	450	5,200	5,400
F. Coli.....	.....		<180	200	.....	<180	580	700
F. Strep.....	.....		1,100	230	.....	46	100	540
Ground water 6.2[a]								
Coli.....	.....		22,000	5,200	1,700	18	<2	33
F. Coli.....	.....		200	<180	<180	<18	<2	<2
F. Strep.....	.....		200	280	490	<2	<2	<2
Lake 4 inlet								
Coli....	1,300	7,900	4,900	4,900	1,700	3,300	3,500	1,400
F. Coli..	78	<180	<180	200	<180	78	270	20
F. Strep.	130	1,300	450	220	400	1,100	300	140
Lake 4 inlet (A.Cl.)								
Coli.....	.....	.....	.....	.....	.....	4.5	2	2
F. Coli.....	.....	.....	.....	.....	.....	<2	2	2
F. Strep.....	.....	.....	.....	.....	.....	<2	2	2
Lake 4 outlet								
Coli....	23	460	4,900	390	270	240	200	78
F. Coli..	5	<18	20	<18	45	11	200	78
F. Strep.	22	49	45	4.5	49	<18	36	13

[a] Obtained from ditch prior to and from pipe after April 1963.

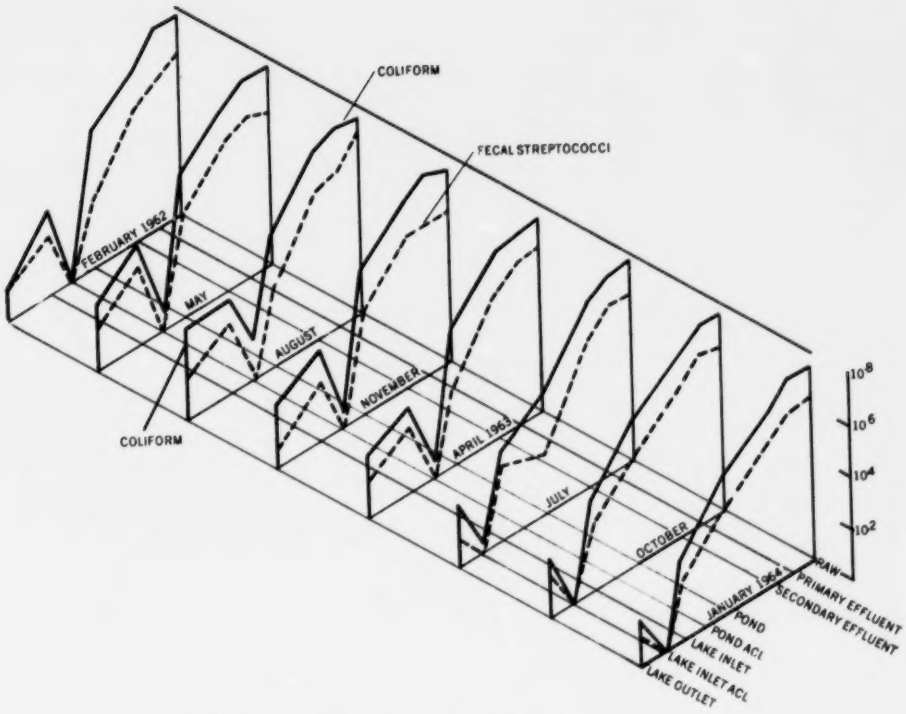

Figure 11. Quarterly range of the median counts of coliform and fecal streptococci.

Table 15. BACTERIAL SUMMARY COLIFORM, FECAL COLIFORM, FECAL STREPTOCOCII IN MPN/100 ml (11:00 am MONDAY DETERMINATIONS, SAN DIEGO DEPARTMENT OF PUBLIC HEALTH)

	July-Dec. 1962		Jan.-June 1963		July-Dec. 1963	
	Range	Med.	Range	Med.	Range	Med.
Plant inlet						
Coli x 10^6	6.8 to 350	79	4.5 to 350	49	2 to 240	49
F. Coli x 10^6	3.5 to 79	33	2.0 to 130	11	<1.8 to 170	17
F. Strep x 10^6	0.5 to 5.6	1.2	0.5 to 5.8	1.3	0.86 to 8.1	1.4
Primary effluent						
Coli x 10^6	9.2 to 540	49	13 to 130	49		
F. Coli x 10^6	2.4 to 140	23	2.0 to 33	11		
F. Strep x 10^6	0.12 to 6.8	1.3	0.69 to 5.0	1.6		
Secondary effluent						
Coli x 10^6	0.64 to 54	5.4	0.79 to 24	9.2	3.3 to 24+	5.4
F. Coli x 10^6	0.35 to 24	2.4	0.045 to 16	2.4	0.02 to 9.2	2.5
F. Strep x 10^6	0.04 to 2.4	0.27	0.01 to 0.96	0.33	0.18 to 0.80	0.40
Pond (B. Cl.)						
Coli x 10^3	13 to 2,400+	240	45 to 2,400+	540	12 to 2,400+	160
F. Coli x 10^3	4 to 1,600	50	4.5 to 1,600	79	1.3 to 2,400+	20
F. Strep x 10^3	<0.1 to 130	3.7	<0.1 to 13.6	4.6	0.3 to 13	3.7
Pond (A. Cl.)						
Coli	<2 to 2,400+	17	<2 to 2,400+	13	<2 to 2,400+	2
F. Coli	<2 to 2,400+	2	<2 to 2,400+	2	<2 to 7.8	<2
F. Strep	0 to 40	0	0 to 4,250	0	0 to 110	0

Table 16. COMPARISON OF MEDIANS DETERMINED BY THE SAN DIEGO COUNTY HEALTH DEPARTMENT AND THE CALIFORNIA STATE HEALTH DEPARTMENTS— COLIFORM, FECAL COLIFORM, AND FECAL STREPTOCOCCI IN MPN/100 ml

		Jan. 1962 to Apr. 1963			July 1963 to Jan. 1964		
		Coli	F.C.	F.S.	Coli	F.C.	F.S.
Water before infiltration	SHD[a]	4.5	<2	2	330,000	130,000	10,200
	CHD	15	2	0	160,000	20,000	3,700
Recovered water — 6.1	SHD				5,200	580	100
	CHD				920	6.8	20
Recovered water — 6.2	SHD				18	<2	<2
	CHD				4.5	<2	0
Lake inlet	SHD	4,900	<180	400	3,300	78	300
	CHD	1,600	49	850	3,300	<180	640
Lake inlet (after chlorination)	SHD				4.5	<2	<2
	CHD				<2	<2	0
Lake 4 outlet	SHD	390	<18	45	200	78	<18
	CHD	170	4	10	170	13	30

		Total record — millions/100 ml. (except F.C.)		
		Coli	F.C.	F.S.
Plant inlet	SHD	49	33%	1.65
	CHD	49	35%	1.3
Primary	SHD	52	33%	1.5
	CHD	49	35%	1.4
Secondary	SHD	15	46%	0.49
	CHD	5.4	44%	0.33
Pond	SHD	0.33	<27%	0.0042
	CHD	0.24	21%	0.0037

[a] SHD is San Diego County Health Department; CHD is California State Health Department.

lower by a factor of a hundred than water entering Lake 4. Chlorination of water entering Lake 4 usually produced a low MPN but did not change the bacterial character of water leaving the lake. The effectiveness of chlorination was decreased when maximum water temperatures occur.

A plot of the median MPN's made by the County Laboratory for the two systems of chlorination is shown in Figure 12. With chlorination at a dose of 10 to 15 ppm and a combined starch-iodide residual of from 3.5 to 9.3 ppm, the coliform concentration of the water recovered after percolation was consistently greater than that of the water spread on percolation beds. A few tests run on aftergrowths during the quarterly sampling periods showed that the Oxidation Pond waters chlorinated to a MPN of less than 2 per 100 ml did not recover in a bottle environment, and that the MPN of waters from the stream decreased with time as the MPN of the waters of Lake 4 did. With chlorination at

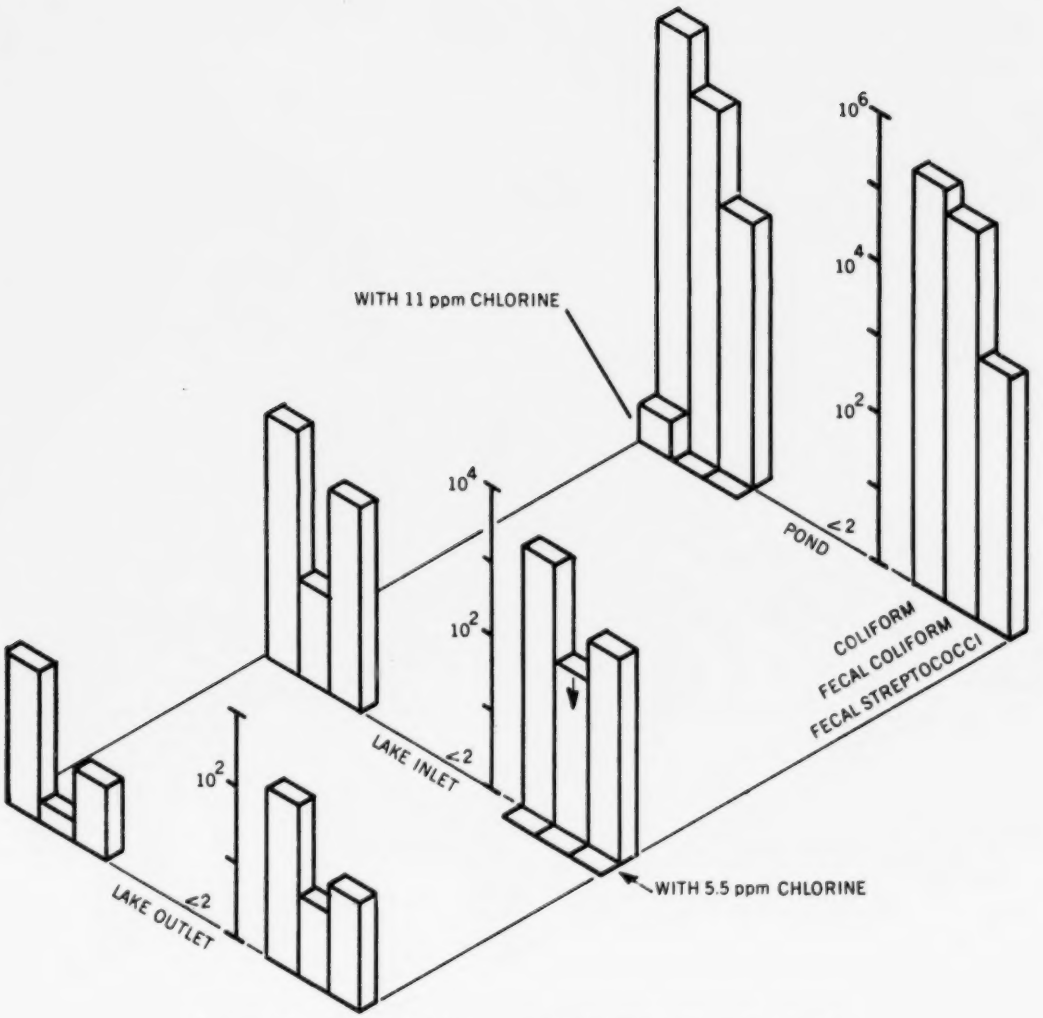

Figure 12. Effect of chlorination on Santee Recreation Project waters – median MPN/100 ml.

the lake inlet, lower doses of about 5 ppm gave a residual of 1 to 5 ppm after a nominal 30 minutes' contact.

Figure 13 shows the relation of the maximum, minimum, and median counts for all three bacterial indicators through a series of frequency curves. This plot was made for two equivalent 9-month records before and after the change in the chlorination location. For each record a similar calendar period from July through March was used to minimize the transition effects in the ground. These frequency curves show the greater effectiveness of chlorination after spreading, and the relative increase in fecal streptococci percentages after spreading. The bacterial concentrations in Lake 4 waters did not change between the two systems. Apparently the bacterial concentrations in Lake 4 bear a greater relation to the environment than to the history of the water.

All maximum MPN's at the lake inlet were associated with turbid waters created by runoff or excavation work in the area.

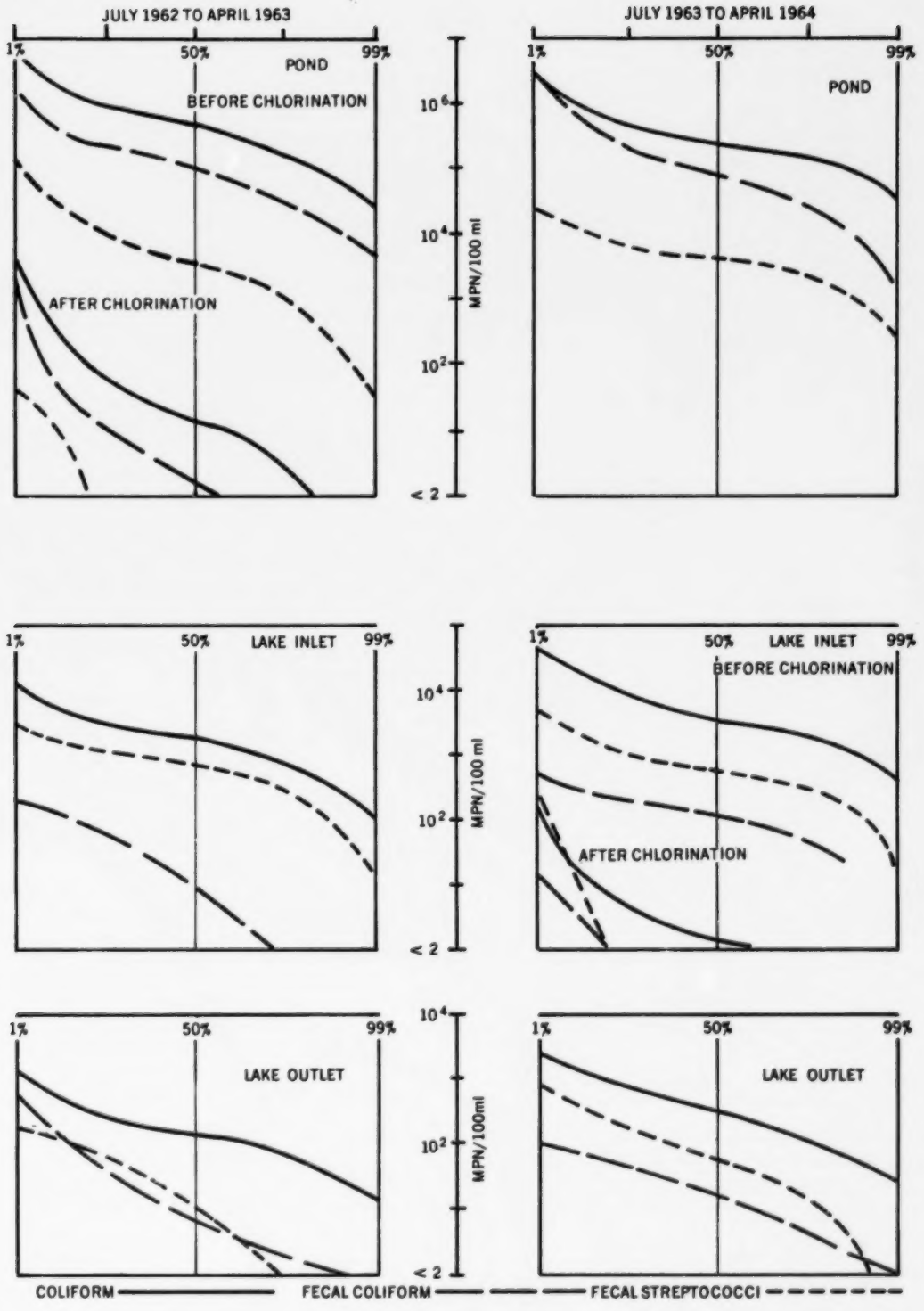

Figure 13. Effect of chlorination on coliform, fecal coliform, and fecal streptococci – percent frequency of MPN/100 ml.

VIROLOGICAL QUALITY

From July 1962 through April 1963, virus samples were collected at weekly intervals at seven locations at Santee. Since April 1963, the frequency of sampling has been every other week and samples have been collected at only four locations. Special samples of fish and algae have also been examined. Table 17 presents a summary of virus isolations made on the swab samples obtained up to June 1964. All routine virus samples have been collected from gauze swabs immersed in the sewage for 48 to 72 hours. The usual immersion time was over the weekend and pickup time was before 11:00 am each Monday morning when the set of comparative bacterial samples was collected. The samples were delivered to the laboratory in an iced box with each swab contained in a plastic food storage bag. At the laboratory, each virus sample was immediately expressed from the swab after an adjustment of pH and concentrated by centrifugation before storage at -65°C. As tissue cultures became available, concentrated specimens of virus were innoculated into two tube cultures each of primary monkey kidney and primary human amnion cells. Selected specimens were also inoculated into tube cultures of Hela cells. Incubation was at 36°C, and microscopic examinations were made each day or two for cytopathic effects. Identification was made by determining what specific antiserum would neutralize the destructive effect of the virus on the tissue cells.

Table 17. VIRAL IDENTIFICATIONS AT SEVEN SANTEE LOCATIONS[a]

Location	No. of tests	%+	Polio 1	Polio 2	Polio 3	Echo	Cox. A & B	Reo virus	Adeno virus	Total
Plant inlet	61	100	27	18	18	40	10	33	29	175
Primary effluent	38	100	17	25	16	30	11	21	17	137
Secondary effluent	53	96	12	14	9	17	6	44	18	120
Oxidation Pond (before chlorination)	63	16	0	2	0	3	0	6	0	11
Oxidation Pond (after chlorination)	36	8	0	0	0	1	0	2	0	3
Lake 4 inlet	61	0	0	0	0	0	0	0	0	0
Lake 4 outlet	54	0	0	0	0	0	0	0	0	0

[a] The table represents test results for about 350 samples through June 1964. The Echo types include 3, 7, 8, 9, 11, 12, 14, 19, 20, and 21. The Coxsackie types include A13, A18, B1, and B3. One grab sample of secondary effluent was positive for Reovirus. Eight samples of fish from Lake 4 were negative for virus.

The results in Table 17 show that all samples of the sewage as it enters the plant and the primary effluent, have given positive results, with the raw sewage averaging about three virus types per sample. The activated-sludge effluent had only two types per sample. Only 11 virus isolations were made from the Oxidation Pond effluent, three from the pond effluent after chlorination, and none from the lake inlet or

outlet. The collecting efficiency of the swab at the effluent from the Oxidation Pond was probably less than at other locations because of lower velocities in a larger channel.

The feeding of the Sabin oral vaccine created a large multiplication of virus particles in the Santee system where 60 percent of the population took Types 1 and 2. A summary of plaque counts made from samples collected before and after this feeding is shown in Table 18.

Table 18. PLAQUE-FORMING UNITS, BEFORE AND AFTER SABIN FEEDING[a]

Location	Before vaccine	After vaccine		
		1	2	3
Plant inlet	1.0	276	20	244
Primary effluent	....	244	25	162
Secondary effluent	....	24	6	18
San Diego raw	0.5	108	19	124

[a] The counts were made at the Robert A. Taft Sanitary Engineering Center on an unconcentrated swab sample.

Biology

Biological studies at the Santee Reclamation Project have been made in an attempt to obtain a working knowledge of the ecology as it relates to the Santee lakes. The Santee Reclamation Project area is located in a region described as Californian or California prairie—a semi-arid region with hot, dry summers and a single growing season during the winter months of maximum rainfall, December, January, and February. The project site is in a canyon. The hills around the canyon and the canyon floor are covered with weedy annuals, chiefly grasses and scattered clusters of shrubs and broad-leaf evergreens. The canyon floor is relatively densely wooded with sycamore, oak, and thick clumps of chaparral. The combination of a grass land habitat, the availability of water, and the close proximity of human dwellings provide an environment conducive to populations of rodents and aquatic vertebrates. The combination of water and shelter in the canyon has the potential of attracting additional fauna.

A fishery has been initiated in Lakes 3 and 4. The continuing success of this fishery demonstrates the ability of the lakes to support and protect a chain of producers and consumers. The biological studies in the area should provide a basis for comparison under future operating changes and perhaps indicate what optimum procedures should be to continue this successful fishery.

The biological sampling program has included the Oxidation Pond and the other two lakes, along with one of the associated waterways. All the work was confined to the Oxidation Pond and Lake 4 during the first 9 months of 1962. Beginning in October 1962, a more intensive

program of plankton sampling along with chemical and physical analyses in Lake 4 was inaugurated in addition to the regular quarterly samplings. Work on the fisheries aspects has proceeded according to the needs of the study without a regular sampling schedule. The Vector Control Study went on a routine basis in July 1962 and has been continued with regular visits, usually on alternate weeks.

PHYTOPLANKTON

The composition and relative abundance of phytoplankton populations were measured originally at Station 4 in the Oxidation Pond, at Station 5 from the pipeline after chlorination of the pond effluent, and at the inlet and outlet of Lake 4. Since October 1962, sampling of Lake 4 has consisted of three stations (B1, B2, and B3) including depth samples at varying depths from 2 to 8 feet. These sampling locations are shown in Figure 14. In addition to the collection and counting of plankton samples, dissolved oxygen determinations, temperature readings, and other chemical measurements were made so that their relationship to the plankton counts could be determined. The Oxidation Pond waters sampled at the outlet (Station 4 and Station 5) have contained 24 genera of algae as shown in Table 19. The predominant genera for the 1962 year are shown in Table 20. The numbers used are the average count for each genus within each quarterly sampling period. In 1963, both numbers and biomass determinations were made for the weekly samples. These have been summarized by month in Table 21. The information in Tables 20 and 21 shows the algae populations characteristic of oxidation pond and lake waters.

During 1962, Chlorella maintained a clear predominance in the Oxidation Pond but was replaced by Oocystis in 1963. The greatest biomass was produced by Euglena in March 1963. A plot of the physical and chemical characteristics related to routine weekly samplings of the Oxidation Pond is shown in Figure 15.

The algae in the Oxidation Pond are characterized by a rather uniform bloom from June to December, 1963. The biomass stayed relatively low even though counts of algae increased in December. The uniformity in phytoplankton was probably related to the uniformity of flow and BOD loading at the inlet. The dissolved oxygen and percent saturation of oxygen were low on the first of October and during late October and November. The first depression of oxygen was caused by strong, hot easterly winds and the later depression was due to the fall overturn period, as shown by the 10°F temperature drop that took place during this time. The first loss of oxygen was accompanied by high alkalinity, which resulted from the loss of photosynthetic activity by algae known to utilize bicarbonate alkalinity. Orthophosphate and total phosphate also increased on October 1 as a result of reduction in photosynthesis. No change occurred in nitrogen early in October, but during the overturn period in late October, ammonia nitrogen increased. This increase was due to the ammonia released from bottom deposits. In general, changes in the phytoplankton in the Oxidation Pond primarily reflect changes in weather.

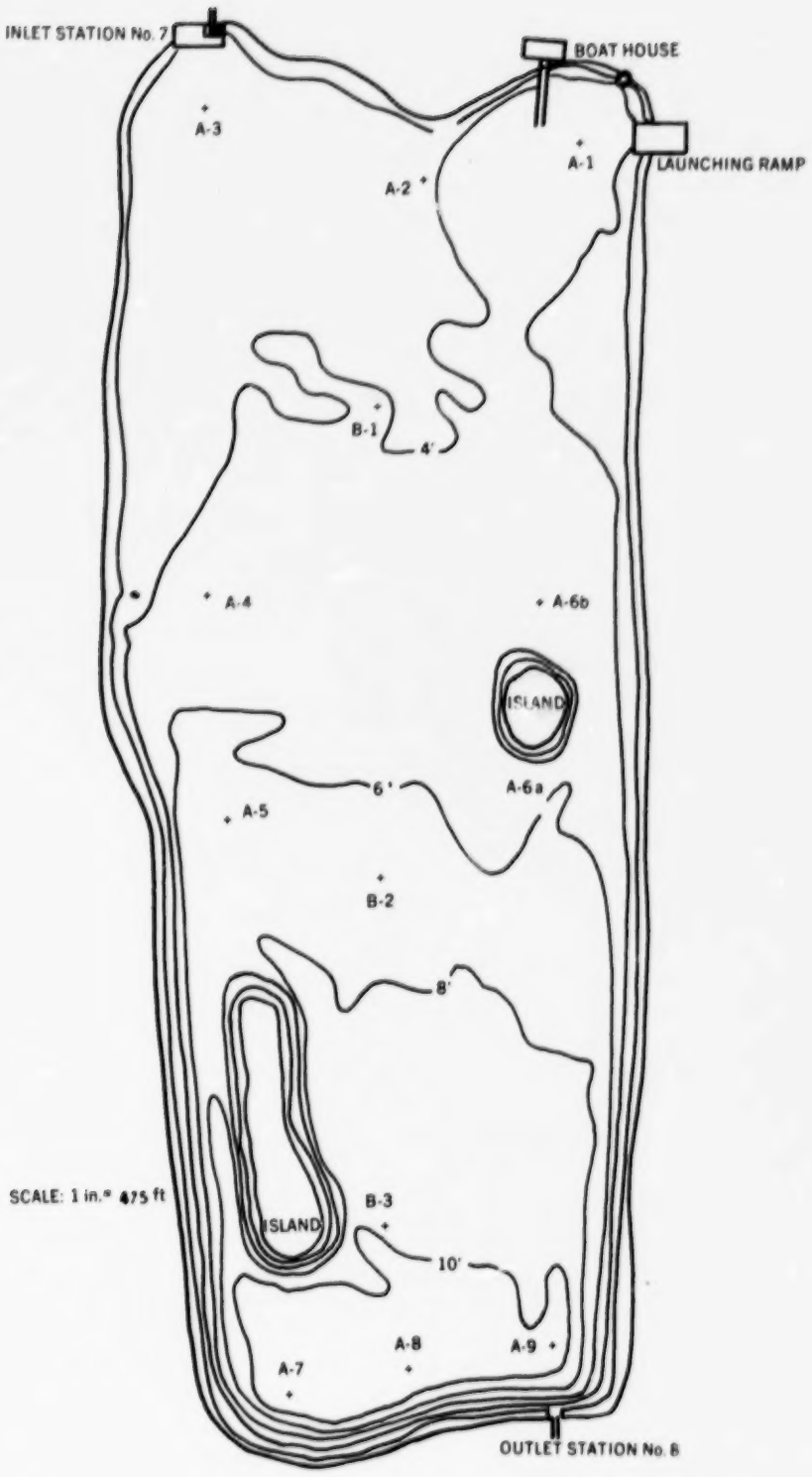

Figure 14. Biological sampling stations in Lake 4.

Table 19. GENERA OF PHYTOPLANKTON OCCURRING IN THE OXIDATION POND AND LAKE 4 INLET AND OUTLET – FEBRUARY 1962 TO JANUARY 1964

Group	Genus	Oxidation pond	Lake 4 Inlet	Lake 4 Outlet
BLUE-GREEN	Agmenellum			X
	Anacystis			X
	Gomphosphaeria			X
	Microcystis			X
	Oscillatoria	X	X	X
	Phormidium			X
	Raphidiopsis			X
GREEN	Actinastrum			X
	Ankistrodesmus	X		X
	Chlorella	X		X
	Chlorococcum	X		X
	Closterium	X	X	X
	Coelastrum	X		X
	Crucigenia	X		X
	Dictyosphaerium			X
	Elakatothrix			X
	Golenkinia			X
	Kirchneriella			X
	Lagerheimia	X		X
	Micractinium	X		X
	Oocystis	X		X
	Pediastrum			X
	Scenedesmus	X	X	X
	Schroederia	X		X
	Selenastrum	X		
	Sphaerocystis	X		X
	Spirogyra		X	
	Staurastrum			X
	Stichococcus			X
	Tetradesmus			X
	Tetraedron			X
	Uronema			X
FLAGELLATES	Carteria	X		X
	Chlamydomonas	X	X	X
	Chlorogonium			X
	Chromulina			X
	Chroomonas			X
	Cryptomonas			X
	Euglena	X		X
	Glenodinium			
	Hetromastix			X
	Lepocinclis	X		X
	Nephroselmis			X
	Phacotus	X		X
	Phacus		X	
	Polytomella	X		X
	Sphaerellopsis			X
	Trachelomonas		X	X
DIATOMS	Cyclotella		X	X
	Diatoma			X
	Diploneis		X	
	Gomphonema		X	X
	Melosira			X
	Navicula	X	X	X
	Nitzschia	X	X	X
	Pennularia		X	
	Stephanodiscus			X
	Surirella		X	X
	Synedra	X	X	X

Table 20. THE FOUR MOST ABUNDANT GENERA OF ALGAE COLLECTED AT THE OXIDATION POND AND LAKE 4 DURING THE FOUR QUARTERLY SAMPLING PERIODS IN 1962

Quarter		Oxidation pond Station 4 (before chlorination)		Oxidation pond Station 5 (after chlorination)		Lake 4 Stations 7 and 8	
		Genus	Count	Genus	Count	Genus	Count
First (Feb.)	1	Euglena	28,400[a]	Euglena	156,000	Oscillatoria	1,210
	2	Chlorella	5,100	Chlorella	13,000	Chlorella	650
	3	Polytomella	400	Oscillatoria Scenedesmus	200 200	Polytomella	620
	4	Oscillatoria	250	(No others recorded)		Actinastrum Scenedesmus	37 37
Second (May)	1	Chlorella	112,000	Chlorella	173,000	Navicula	13,500
	2	Chlamydomonas	70,200	Sphaerocystis	64,600	Trachelomonas	7,240
	3	Sphaerocystis	14,900	Chlamydomonas	53,200	Euglena	2,440
	4	Euglena	9,100	Euglena	17,900	Micractinium	2,050
Third (Aug.)	1	Chlorella	103,000	Oocystis	58,900	Euglena	3,860
	2	Oocystis	47,100	Chlorella	56,300	Syndra	1,980
	3	Sphaerocystis	20,000	Sphaerocystis	26,400	Cryptomonas	1,760
	4	Scenedesmus	3,080	Scenedesmus	2,420	Navicula	1,540
Fourth (Nov.)	1	Chlorella	448,000	Chlorella	127,000	Chromulina	12,800
	2	Oocystis	40,500	Scenedesmus	10,800	Nitzschia	3,810
	3	Scenedesmus	32,900	Oocystis	3,810	Chlamydomonas	2,810
	4	Euglena	17,000	Euglena	3,810	Cryptomonas	2,400

[a] All figures are the average of the individual counts within each quarter for the given genus.

Lake 4 presents a considerably different picture than the Oxidation Pond does. Table 19 shows the 53 different genera that were found in Lake 4. The majority of these were green algae. Inlet waters to Lake 4 showed only 14 different genera. Most of these were attached forms of diatoms that had been broken away from the rocks of the streams. No pattern of frequency is apparent. The uniform low count of phytoplankton in lake inlet waters has a low biomass. This phytoplankton count is not related to the plankton in the waters spread, since the spreading basin caused a complete removal of those algae types. The low count shown in Figure 16 is also not indicative of the true photosynthesis occurring in the stream, since it does not reflect the presence of the abundant filamentous forms: Cladophora, Spyrogyra, and Hydrodictyon. The dissolved oxygen in the inlet waters declined below 100 percent saturation about October 1, 1963, and remained at 5 to 10 milligrams per liter through December. Changes in alkalinity occurring in July and August were related to the reduction in streamflow. Both orthophosphate and total phosphate showed an increase when streamflow first increased again, but later dropped back to smaller concentrations. Orthophosphate also increased during October probably as a result of the decay of the filamentous green algae found in the stream. This increase in phosphate was also accompanied by an in-

Table 21. QUANTITATIVE RELATIONSHIPS AMONG THE FOUR MOST ABUNDANT PHYTOPLANKTON GENERA, 1963

Date 1963	Pond 1 outlet			Lake 4 inlet		
	Genera	Avg count/ml	ppm/vol	Genera	Avg count/ml	ppm/vol
Jan.	Chlorella	24,500,000	29.6			
	Selenastrum	271,000	4.1			
	Oocystis	6,500	4.2			
	Chlorococcum	4,800	5.2			
Feb.	Selenastrum	492,000	7.4			
	Oocystis	28,600	22.0			
	Chlorella	27,500	0.35			
	Chlorococcum	6,200	5.2			
Mar.	Oocystis	115,000	91.8			
	Euglena	22,000	234.0			
	Chlorococcum	4,300	6.0			
	Selenastrum	2,020	0.3			
Apr.	Euglena	82,000	190.0			
	Selenastrum	79,700	1.18			
	Oocystis	60,900	34.9			
	Chlamydomonas	16,900	1.9			
May	Selenastrum	170,000	2.75			
	Oocystis	167,000	111.0			
	Chlorococcum	54,200	10.1			
	Chlamydomonas	5,760	0.87			
June	Oocystis	73,500	66.1	Nitzschia	2,028	0.37
	Chlorococcum	20,900	15.3	Closterium	780	0.14
	Euglena	468	13.1	Synedra	624	0.1
	Nitzschia	468	0.3			
July	Oocystis	122,000	101.0	Nitzschia	585	1.43
	Chlorococcum	16,200	19.4	Gomphonema	468	1.22
	Scenedesmus	2,500	2.7	Navicula	117	0.04
	Chlorella	1,120	0.1			
Aug.	Oocystis	132,000	114.0	Nitzschia	468	0.23
	Chlorococcum	18,500	67.0	Gomphonema	352	0.39
	Chlorella	13,100	1.7	Navicula	258	0.04
	Chlamydomonas	1,750	0.3			
Sept.	Oocystis	65,600	47.8	Nitzschia	468	2.6
	Chlorococcum	36,500	14.6	Gomphonema	156	0.25
	Euglena	2,640	61.7	Synedra	156	2.6
	Scenedesmus	1,400	0.3			

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Oct.	Micractinium	76, 800	56.3	Nitzschia	780	1.95
	Ankistrodesmus	9, 500	0.7	Gomphonema	156	0.06
	Chlorococcum	3, 900	3.5	Cyclotella	156	0.04
	Euglena	2, 650	16.8			
Nov.	Selenastrum	101, 000	1.5	Nitzschia	234	1.5
	Micractinium	14, 700	10.9	Gomphonema	234	0.19
	Ankistrodesmus	14, 100	1.9	Diploneis	117	0.19
	Chlorella	2, 700	0.2			
Dec.	Selenastrum	240, 000	3.8	Nitzschia	700	1.1
	Ankistrodesmus	62, 400	11.0	Navicula	468	0.19
	Euglena	10, 800	47.5	Pinnularia	117	0.3
	Chlorella	1, 500	0.2			

	Lake 4 outlet			Lake 3 outlet		
1963	Genera	Avg count/ml	ppm/vol	Genera	Avg count/ml	ppm/vol
June	Ankistrodesmus	8, 658	0.65	Ankistrodesmus	3, 744	0.07
	Heteromastix	8, 190	0.90	Heteromastix	3, 744	0.19
	Nitzschia	2, 808	0.14	Kirchneriella	2, 184	0.32
	Kirchneriella	2, 574	0.39	Chroomonas	1, 248	0.21
July	Kirchneriella	75, 933	11.38	Phormidium	42, 588	1.4
	Ankistrodesmus	23, 141	0.42	Kirchneriella	16, 380	2.45
	Scenedesmus	3, 120	0.24	Anabaena	11, 700	31.97
	Cryptomonas	2, 808	6.78	Chlorella	2, 808	0.5
Aug.	Kirchneriella	34, 977	5.24	Phormidium	10, 179	0.76
	Nitzschia	10, 140	0.2	Kirchneriella	9, 128	1.37
	Coelosphaerium	9, 204	2.75	Raphidiopsis	3, 744	0.17
	Ankistrodesmus	5, 148	0.08	Chlorella	3, 159	0.44
Sept.	Kirchneriella	15, 142	2.3	Raphidiopsis	61, 776	2.78
	Ankistrodesmus	26, 881	0.4	Kirchneriella	7, 176	1.08
	Cyclotella	10, 296	0.63	Chlorella	6, 708	0.94
	Scenedesmus	2, 024	0.13	Oscillatoria	2, 904	39.62
Oct.	Ankistrodesmus	139, 152	2.09	Ankistrodesmus	17, 160	0.3
	Kirchneriella	58, 823	8.79	Kirchneriella	15, 132	2.27
	Raphidiopsis	20, 748	0.22	Raphidiopsis	12, 012	0.54
	Scenedesmus	6, 708	1.4	Cyclotella	7, 176	3.29
Nov.	Kirchneriella	28, 782	4.3	Raphidiopsis	24, 453	1.1
	Ankistrodesmus	12, 288	0.18	Chaetoceros	20, 475	3.89
	Raphidiopsis	11, 355	0.12	Kirchneriella	10, 179	1.53
	Scenedesmus	6, 013	2.21	Cyclotella	6, 552	3.08
Dec.	Kirchneriella	44, 223	6.63	Chaetoceros	69, 264	3.29
	Ankistrodesmus	10, 413	0.15	Raphidiopsis	19, 539	0.22
	Scenedesmus	4, 095	1.24	Kirchneriella	4, 020	0.25
	Nitzschia	3, 588	0.07	Ankistrodesmus	1, 489	0.01

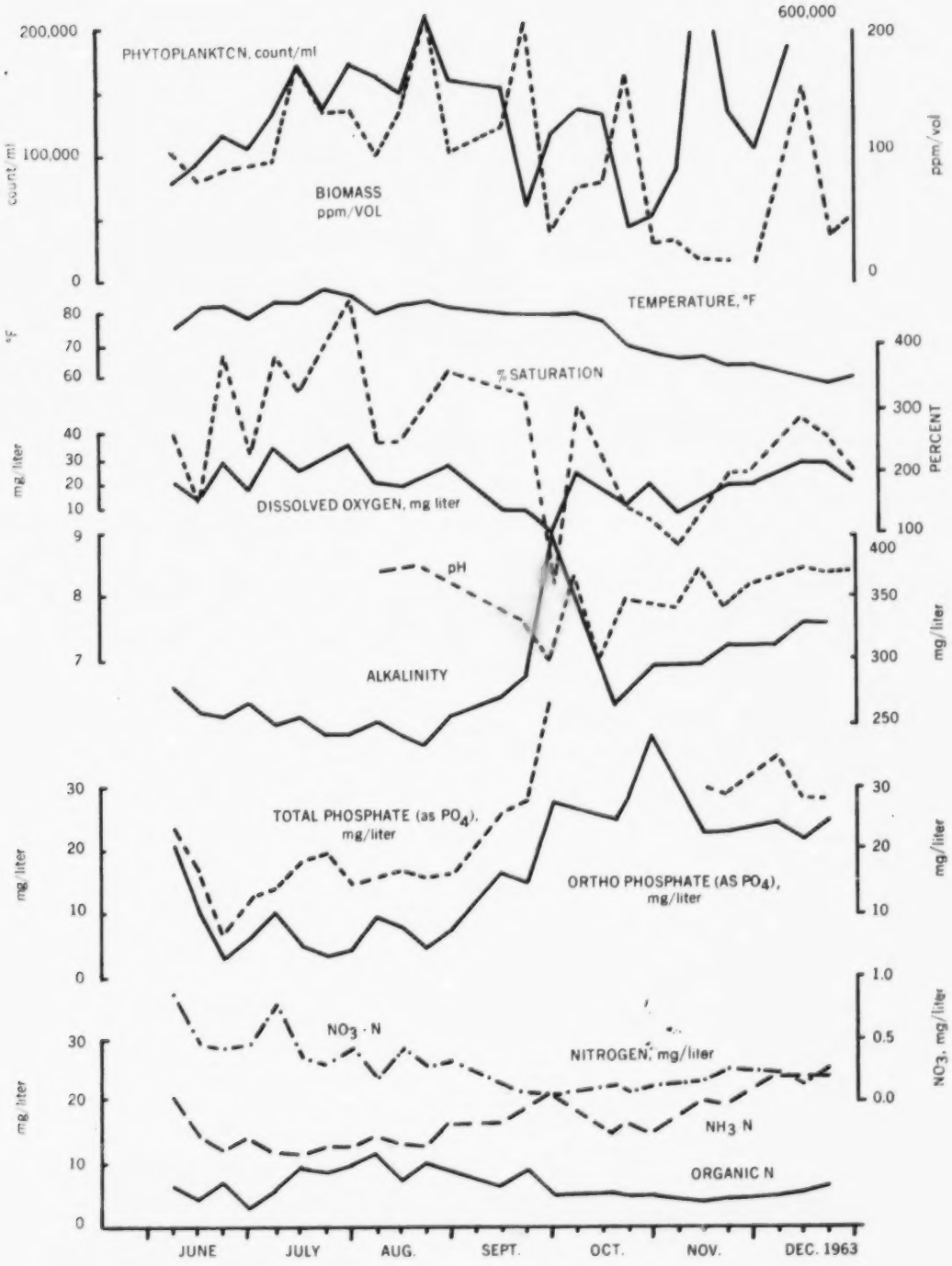

Figure 15. Interrelations of phytoplankton with physical and chemical quality of Pond 1 outlet water.

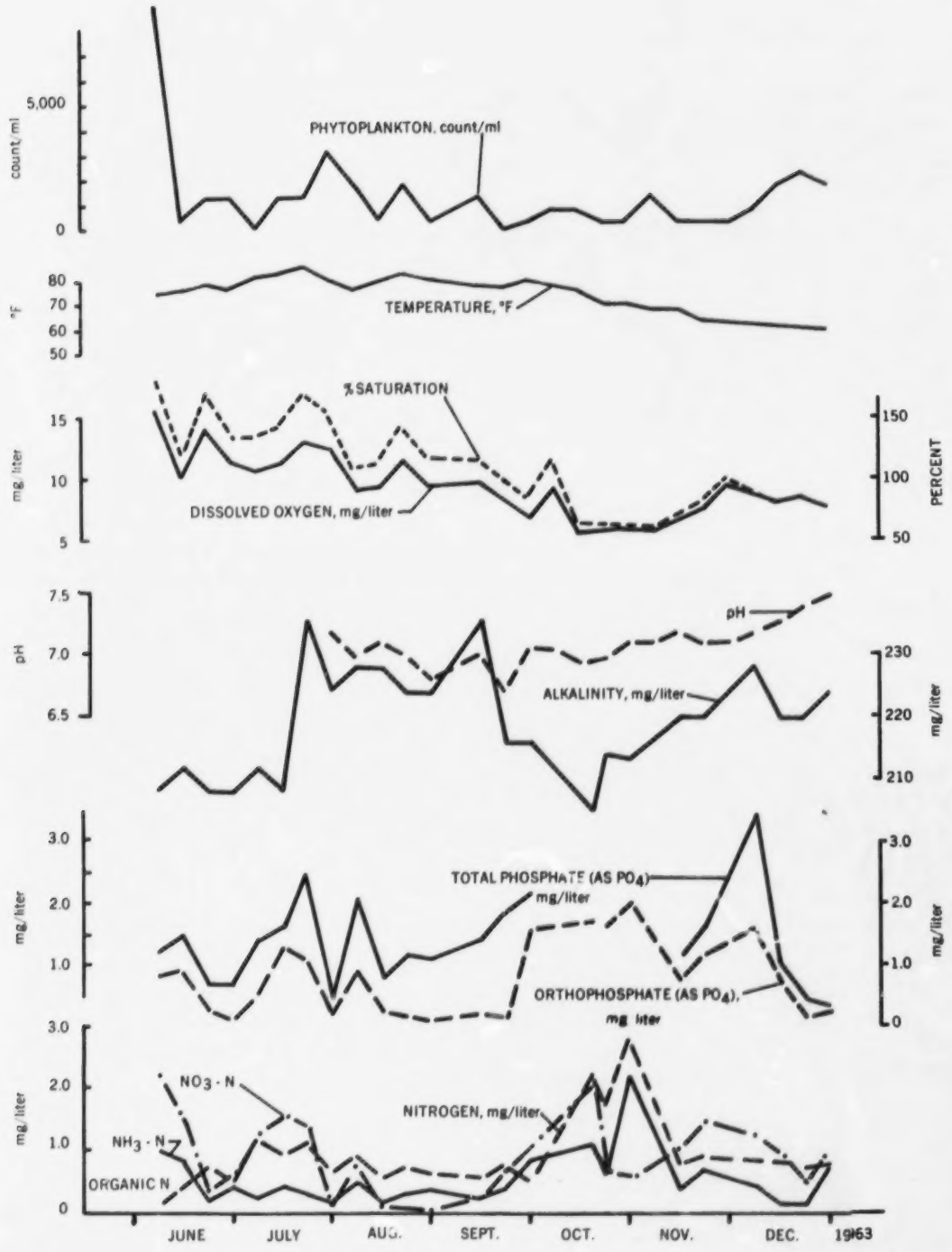

Figure 16. Interrelations of phytoplankton with physical and chemical quality of Lake 4 inlet water.

crease in organic nitrate and ammonia nitrogen forms. In general, algal activity in the stream has been dependent upon fluctuating flow and weather conditions.

Numerical relationship of algae in Lake 4 are shown in Tables 20 and 21. Very few genera repeated their appearance among the most numerous four types during both 1962 and 1963. The biomass in Lake 4 was much greater than in inlet waters, but was still much smaller than in the Oxidation Pond. The genus Kirchneriella reached a peak most frequently.

The intensive sampling schedule conducted in Lake 4 covered a series of stations along the center traverse of the lake as shown in Figure 14. The results of this intensive sampling are shown for a 6-month period in 1963 along with physical and chemical parameters in Figure 17. From this data and reference to Table 21, changing predominance and changing counts can be related to nutrient levels entering the lake. Resulting changes in alkalinity and pH can also be noted. A check on depth distribution showed that the diatoms were more abundant near the bottom whereas the other groups of algae yielded higher counts in the surface samples.

The algae in Lake 4 had two pulses of significance, both in count and biomass. These pulses were related to increased orthophosphate entering the lake and tended to show an immediate response. Depressions in alkalinity resulted from both blooms. The second bloom corresponded with a considerable buildup of organic nitrogen and also a short-term increase of both nitrate and ammonia nitrogen. Both blooms increased dissolved oxygen, and the second bloom was followed by a depression of oxygen to slightly less than 100 percent saturation for the only time during the year. This depression was accompanied by a 10°F temperature drop and occurred during a turnover period when the crop of algae was declining. Both dissolved oxygen and temperatures stratify in Lake 4 (Figure 18). The sharp change in dissolved oxygen during February 1963 can be explained by heavy winds which caused mixing and increased oxygen demand from bottom deposits. A plot of diurnal dissolved oxygen and temperatures in Figure 19 also shows the equalization in overnight oxygen and temperature for this February 12 to 13 period. Significantly, only a few shad were killed by this upset, but the warning of the possible damage that could result from these sudden changes is apparent.

The waters of Lake 3 also produced two blooms as shown in Figure 20. The early bloom came in July and was probably caused by the decreased flow coming through from Lake 4. This bloom was accompanied by a very great decrease in alkalinity and a large increase in organic nitrogen. This was due to the ability of the phytoplankton genus Anabaena both to split inorganic bicarbonates and to extract nitrogen from the air in the production of their body cells. The later bloom of algae was also a blue-green type and came late in September. This bloom could have resulted from the increased flow at that time. The phytoplankton in both of the lakes was thus seen to be primarily dependent upon nutrient changes brought about by nonuniform flow conditions.

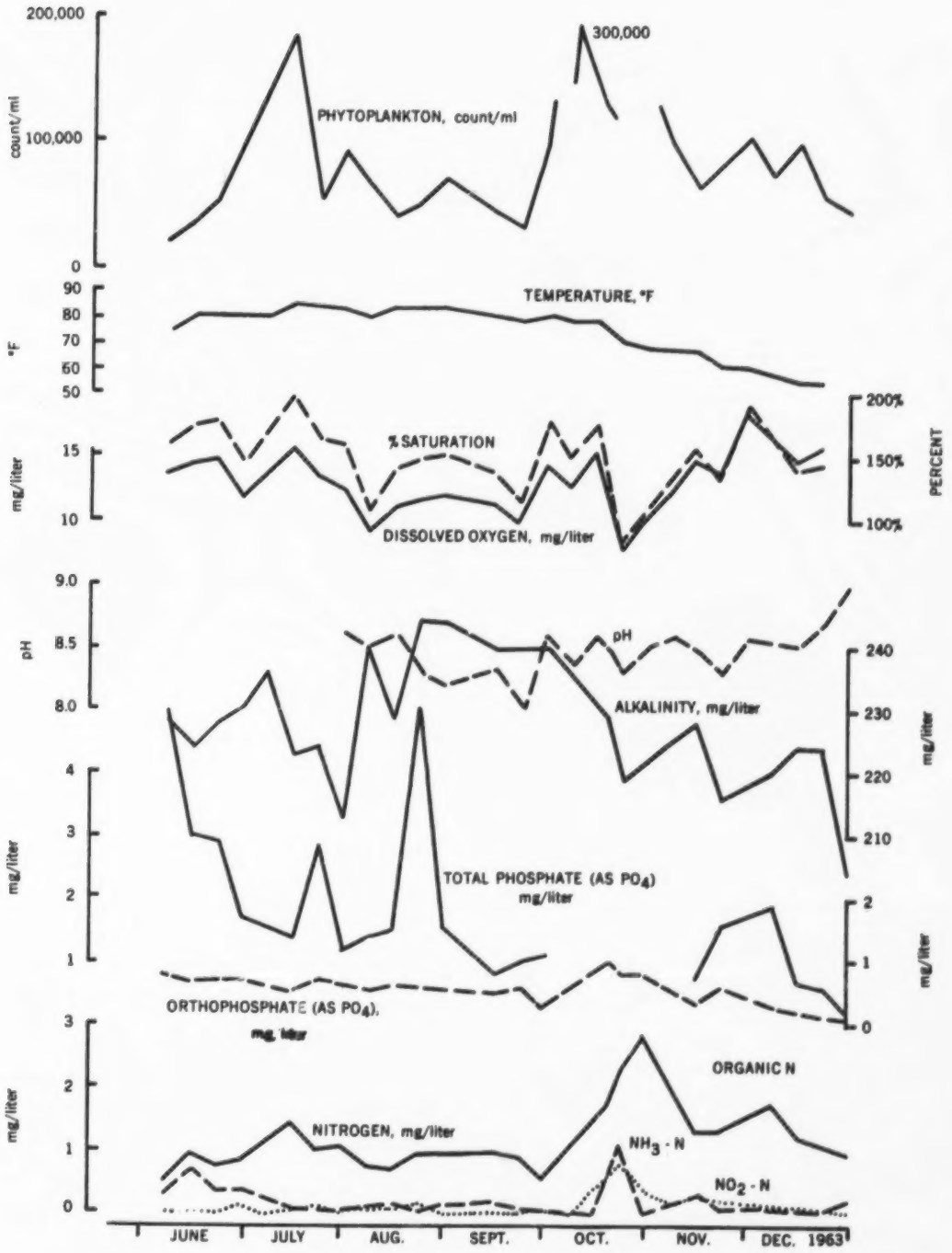

Figure 17. Interrelations of phytoplankton with physical and chemical quality of Lake 4 outlet water.

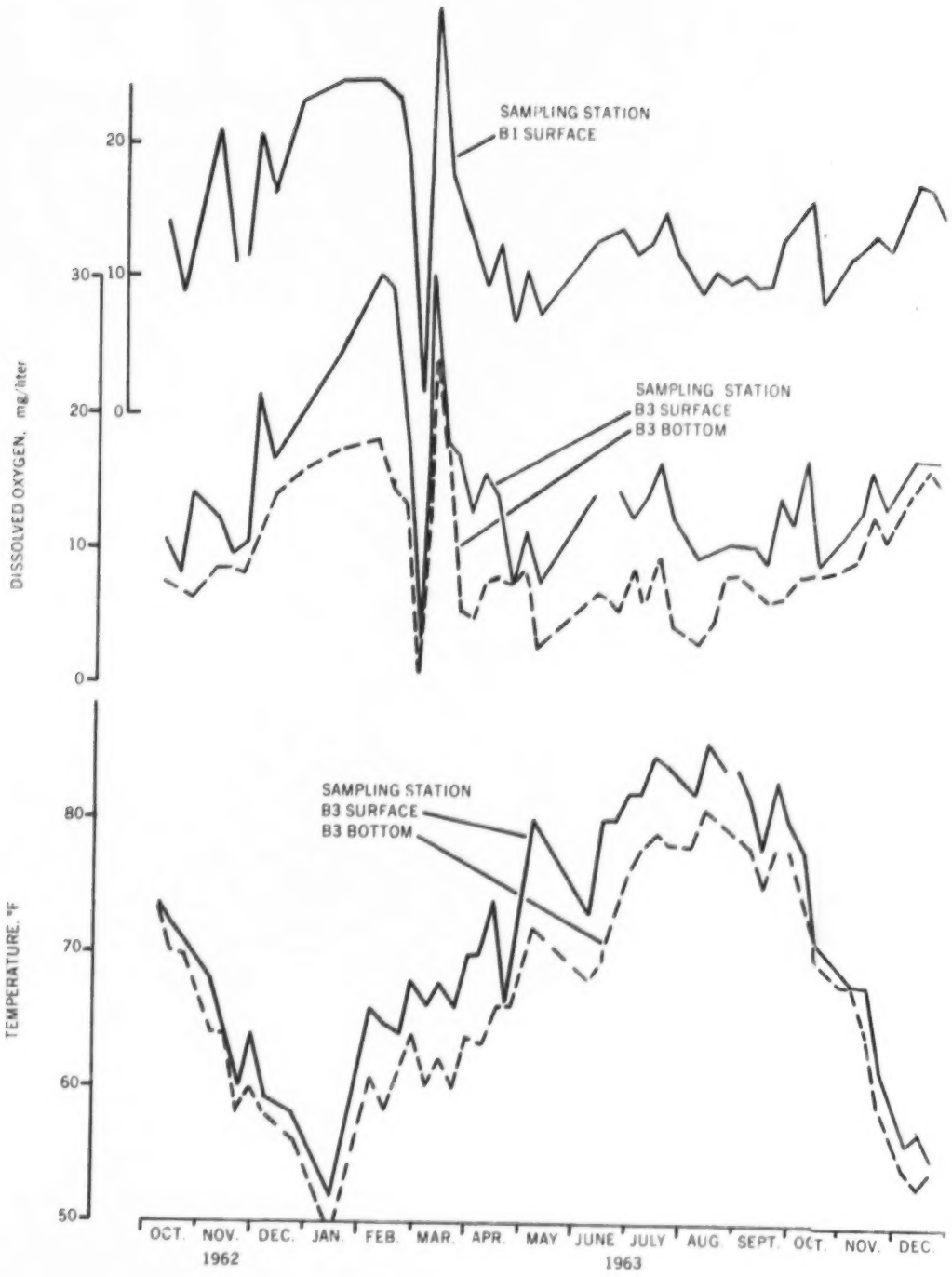

Figure 18. Stratification of temperature and dissolved oxygen in Lake 4.

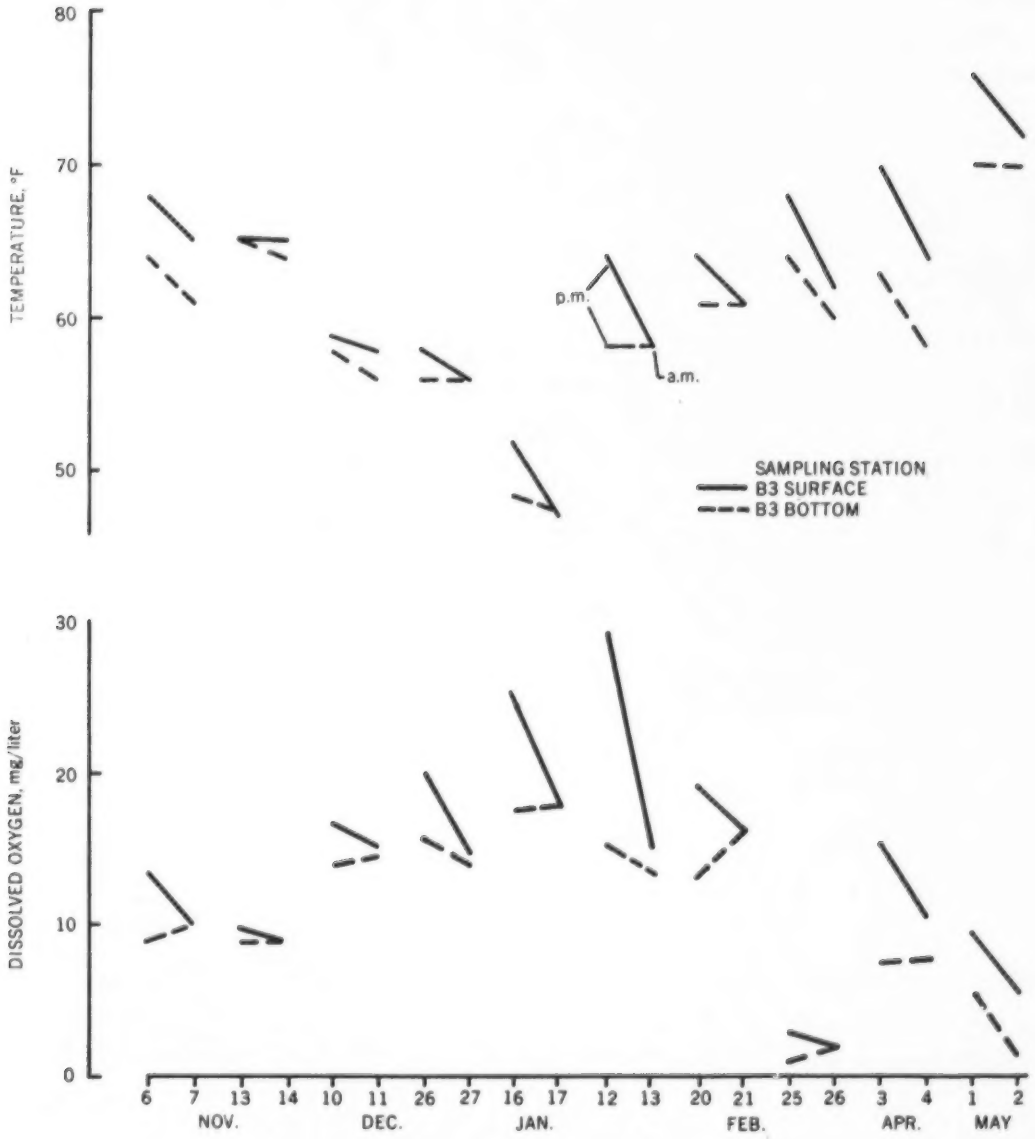

Figure 19. Diurnal temperature and dissolved oxygen at sampling station B3 in Lake 4.

AQUATIC FLOWERING PLANTS

Rooted aquatic plants are present in Lakes 3 and 4. None of them, however, have yet become a problem. Rooted aquatics have also been found in Lake 2, but after the change in operation in which Lake 2 received chlorinated plant effluent, all species died out. Similar rooted aquatics have also been found in the streambed near the lakes. Two genera of plants have been identified: Chara and Potamogeton. Rooted plants have generally been restricted in growth by continuing turbidity. Their appearance has been noted only during the April to October period.

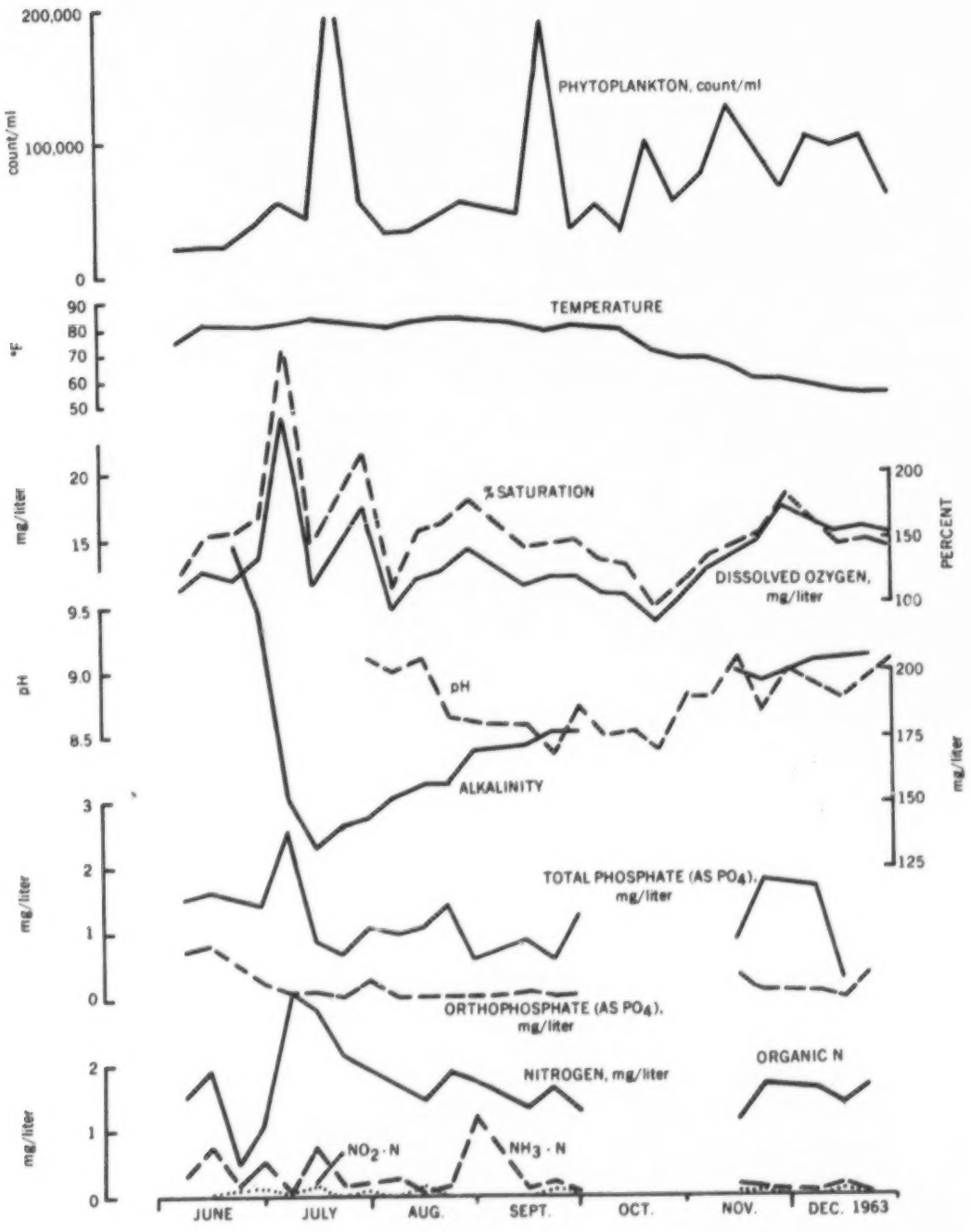

Figure 20. Interrelations of phytoplankton with physical and chemical quality of Lake 3 outlet water.

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ZOOPLANKTON

The Oxidation Pond zooplankton are of negligible importance. In treatment, they have been more of a detriment than an asset to oxidation processes since at times they consume the primary oxygen producers and also exert an oxygen demand. The only possible beneficial aspect is that they are consumers of detritus and bacteria.

Table 22 shows the numbers of three groups of zooplankton that occurred throughout the year of 1963, at Pond 1 outlet. Three full peaks occurred, one in the spring, one in the middle summer, and one in the fall. The peak in the fall coincided with a decrease in phytoplankton and a septic condition in the pond during September.

Table 22. NUMBERS OF THREE GROUPS OF ZOOPLANKTON THAT OCCURRED AT POND 1 OUTLET DURING 1963

1963	Count/liter Rotifers	Cladocerans	Copepods
February . .	144	55	0
March	1,530	1,430	0
April	470	138	0
May	7,140	229	5
June.	20	236	0
July	367	1,117	1
August	9,115	407	0
September .	60	3,270	0
October . . .	2,080	310	0
November . .	1,640	115	0
December . .	7,440	2	0

Lake 4 contains a greater diversity of zooplankton with smaller individual biomasses. This diversity is manifest even from station to station. Although peak blooms do occur in Lake 4, they do not match the numbers occurring in Pond 1. Vertical distribution of the zooplankton is also apparently adequate, since relatively high numbers were obtained even at the deepest sampling station, though of a different type than that found at the surface. This would indicate that foraging areas for fish are not limited to any one territory. Unlike the situation in the Oxidation Pond, zooplankton in Pond 4 play a part in the food chain that is more complete and significant by contributing to the support of the heavy fish populations. Microscopic animal life is also abundant in the masses of filamentous algae lining some areas of the shore. This is available to young fish that frequent these areas after hatching.

BENTHIC ORGANISMS

Benthic organisms are beneficial because they breakdown organic material in the Oxidation Pond and because of their importance in the

food chain developed in the recreational lakes. They can, in turn, become a nuisance, especially in the enriched environment of oxidation ponds because of the lack of predators. The only limitations to benthic types in the Oxidation Pond are occasional depressed oxygen conditions and some inhibiting effects of decaying organic material. Benthic organisms could reduce the recreational use of the lakes when they create a nuisance after emergence. Some benthics can become vectors for disease and these require control procedures. The Vector Control Study at Santee has included some organisms other than the benthic ones. The actual control of mosquitoes at the Santee Lakes and in the other waterways of the project has been practiced continuously since the start of the project, with both mosquitofish and the pesticides Malathion and Baytex being used.

Recreational Lakes 3 and 4 have bottoms that are alike. These are composed of lightly packed conglomerate, with particle sizes ranging from sand to boulders. No really functional sampling gear for this type of substrate has been developed. Good representative samples have, therefore, been limited to the deep end of the lakes where sludge has settled. The Oxidation Pond and Lake 2 have bottoms that are completely covered with a soft sludge.

Beginning in February 1962, the sampling was performed by personnel of the City of San Diego Utilities Department. In July 1962, a regular Vector Control Study was started by the State Department of Public Health. The purpose of this study was to determine the numbers and variations of benthic organisms and to develop control recommendations. A routine sampling program was established on an alternate-week basis, with all lakes and waterways in the projects being covered. The data obtained in the Vector Control Study have been enumerated in Table 23 and plotted in Figure 21. Of primary importance are the Tendipedidae (midges). This form of aquatic midge is a major pest in California. Precise counts of this midge were taken at both sampling stations in the lakes and in light traps near the lakes. Twelve species of Tendipedidae have been collected in the lakes and waterways and 17 species have been found in light traps.

Small numbers of snails (Physa sp.), biting midge (Heleidae) larvae, and dragonfly (Odonata) naiads were found in most waterways. Gnats were collected in fairly large numbers in the channel arising from the spreading basin water and in large numbers in the channel leaving the project. Fortunately, the proximity of homes in the area is such that the flyoff of gnats has not created a major public nuisance. Along with the Sycamore Creek discharge from the project, Ponds 1 and 2 were the most productive sources of these gnats. The numbers of fish and other predatory organisms have greatly restricted the numbers of gnats that have been developed in Lakes 3 and 4. Midge populations were higher in the fall and winter of 1962-1963 than in the following year and this probably resulted from the changing fish populations. The numbers of midges are also reduced to lower levels with the higher summer temperatures, and there is some indication that the abundance of midges was directly related also to oxygen levels.

Mosquito larvae that have been identified included Culex pipiens, C. peus, C. tarsalis, Culiseta inornata, and Anopheles franciscanus. Mosquitoes have presented the most serious problem when vegetation grows along the bank. They are especially serious in the effluent area of Pond 1 and in Pond 2, since mosquito fish cannot be used in this environment. Seepage pools within the area of the proposed Lake 5 and adjacent to or in the bottom of the spreading area have also fre-

Table 23. BENTHIC ORGANISMS COLLECTED AT SANTEE RECREATION PROJECT

Organism	Present	Insects present	
		As larvae	As adults
Annelida			
Oligochaeta (Aquatic earthworms)			
Limnodrilus sp.	x		
Tubifex sp.	x		
Crustacea			
Amphipoda (Scuds)	x		
Insecta			
Ephemeroptera (Mayflies)		x	
Diptera			
Psychodidae (Moth flies)		x	
Telmatoscopus sp.		x	
Culicidae (Mosquitoes)			
Anopheles franciscanus		x	
Culex sp.		x	
Culiseta sp.		x	
Chaoboridae (Phantom midges			
Chaoborus sp.		x	
Simuliidae (Black flies; Buffalo gnats)			
Simulium argus		x	
S. vittatum		x	
Tendipedidae (Midges)			
Tendipes fulvipilus		x	x
T. stigmaterus		x	x
T. attenuatus		x	x
T. nervosus		x	x
T. plumosus		x	x
T. californicus		x	x
T. (Cryptochironomus) monochromus			x
T. (C.) sp.		x	
Polypedilum sp.		x	x
Tanytarsus sp.		x	x
Pelopia sp.		x	x
Procladius sp.		x	x
Pentaneura sp.		x	x
Cricotopus sp.		x	x
Endochironomus nigricans			x
Anatopynia sp.			x
Micropsectra sp.			x
Smittia sp.			x
Unidentified (Several species)			x
Heleidae (= Ceratopogonidae) (Biting midges)		x	
Culicoides sp.			x
Tabanidae (Horseflies)		x	x
Mollusca			
Gastropoda (Snails)			
Physa sp.	x		

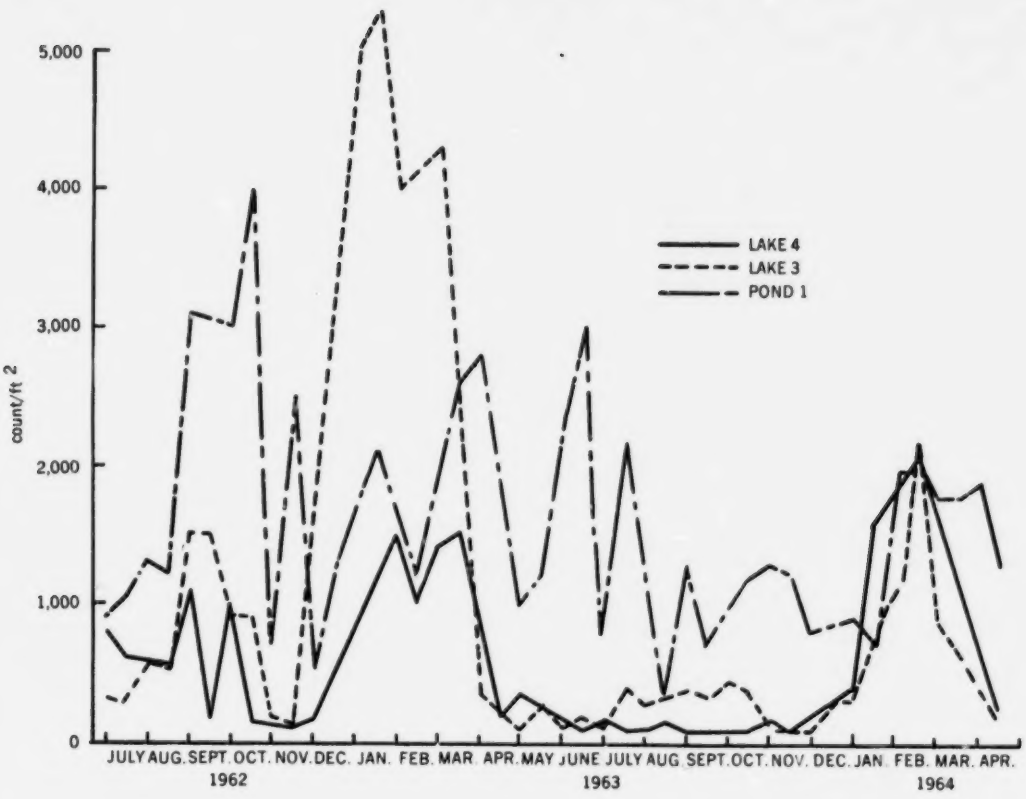

Figure 21. Benthonic organisms per square foot.

quently contained mosquito larvae. Fish life has limited the development of mosquitoes in Lakes 3 and 4, and other control procedures have been provided to keep the shoreline areas clean. For the 2-1/2 years up to the end of 1963, records show that more than 1,300 gallons of larvicide have been used in the project. Approximately 10 percent of the spraying effort has involved the percolation area and the stream above the recreational lakes. No spraying has been necessary in the recreational lakes. The concentration of residual Malathion or Baytex from the use of this 2 percent larvicide solution that could be expected to have entered the recreational lake is approximately 1 part per billion (ppb).

Overall productivity in Lake 4 was further measured by sampling at 13 stations noted on Figure 14. Figure 22 shows the productivity relationships of the various types of substrate present in the lake.

In general the shallow-water stations tended to have higher populations. Predominant forms present were the Tendipedid larvae. The snails and annelids were for the most part shallow-water inhabitants while phantom midges were most numerous in the deeper waters. Other bottom forms—mayflies and dragonflies—were never abundant.

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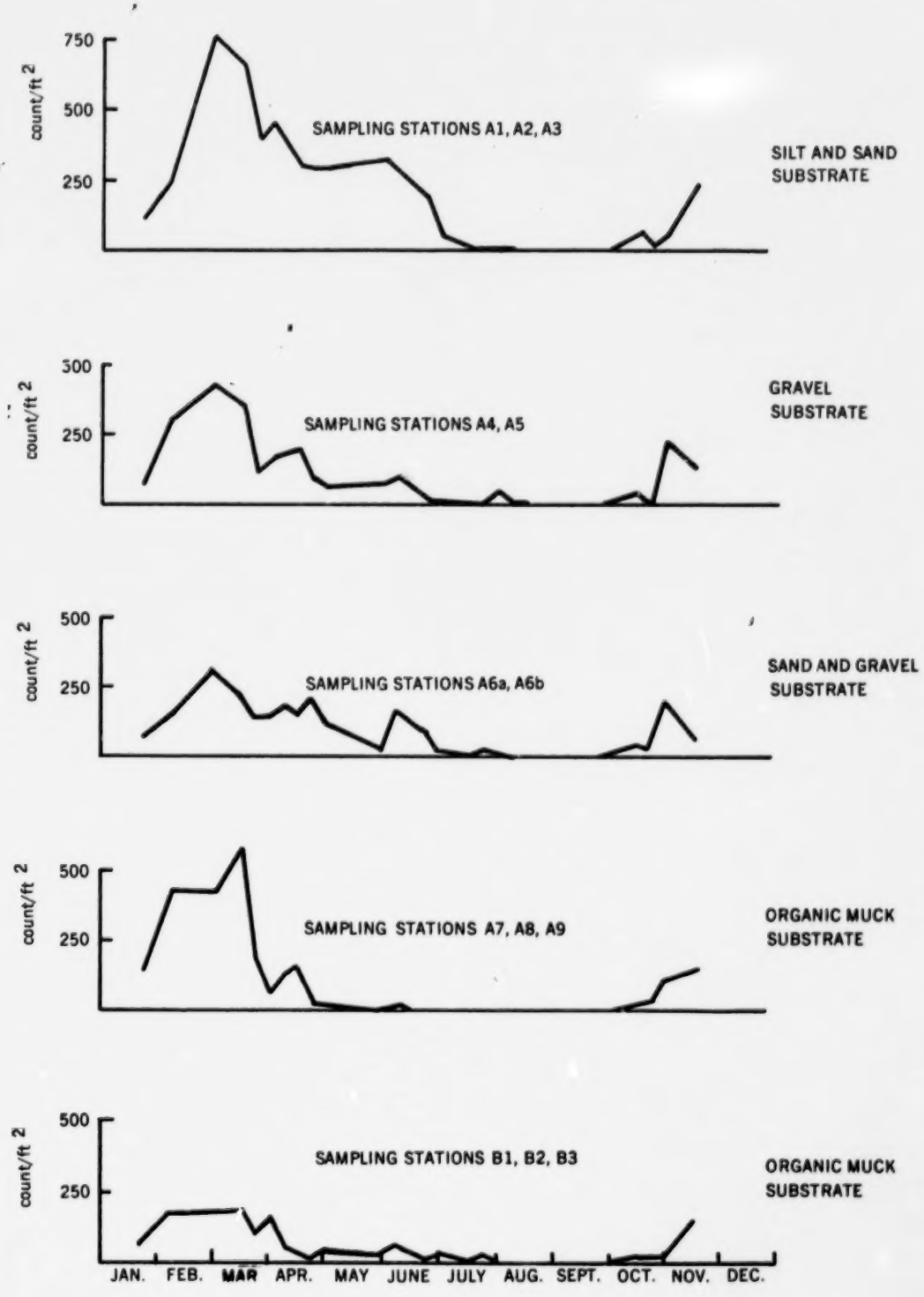

Figure 22. Average number of benthic organisms per square foot, Lake 4.

THE FISHERY

Among the recreational pursuits allowed at the Santee Recreation Project, "Fishing for Fun" has perhaps been the most popular, especially for children. The "Fishing for Fun" program originally required, among other things, that all game fishes (except the sunfishes) must be returned to the water and that all sunfishes must be turned over to an attendant for disposal. The first requirement was based on the principal objective of the Santee Recreation Project to determine whether or not these recreational lakes can be maintained and used without exposing the public to possible infection from harmful bacteria and viruses. Thus, no fish were permitted to be eaten until studies proved that this was safe. The second requirement sought to prevent a buildup of the sunfish population to the detriment of the game fishes, as happens so frequently in farm ponds containing similar combinations of warm-water fishes. The requirements of the fishing program were suspended after the 1964 spawning season. Fish are now allowed to be taken for consumption with catch limits only on bass and catfish.

Since early in 1961, the California State Department of Fish and Game has stocked the lakes with a variety of warm-water fishes. Table 24 shows the planting through 1963. In June 1961, adult redear sunfish, Lepomis microlophus, threadfin shad, Dorosoma petenense, and yearling largemouth bass, Micropterus salmoides, were planted in Lake 4. Six months later, adult channel catfish, Ictalurus punctatus, were also planted there. In addition, 19 rainbow trout, Salmo gairdnerii, were put in the lake during the 1961-1962 winter season by others. Lake 3 received plants of Florida largemouth bass, threadfin shad, and channel catfish between June 1961 and October 1962.

Table 24. RECORD OF FISH PLANTING BY DEPARTMENT OF FISH AND GAME IN SANTEE LAKES [a, b, c]

Date	Largemouth Bass	Channel Catfish	Threadfin Shad	Redear Sunfish
		LAKE 3		
6-21-61			1,000	
3-27-62	118 (Florida)			
10-15-62		700		
		LAKE 4		
6-20-61	90 (Calif.)			50
6-21-61			1,000	
12-15-61	62 (Calif.)	25		
10-15-62		300		

[a] One hundred fresh-water shrimp, Palaemoetes paludosus, were planted in Lake 2 on July 6, 1962.

[b] Rainbow trout were also planted in Lake 4 in 1961 by others than Department of Fish and Game: 11 on Nov. 20, 1961 and 8 on Dec. 8, 1961.

[c] Bluegill were planted (12) in Lake 4 on May 15, 1961.

Follow-up test seinings showed that in addition to the fish species officially planted, Lake 4 also supports other species. Bluegill sunfishes, Lepomis machrochirus, are now present, presumably from an unauthorized plant. Mosquitofish, Gambusia affinis, are also present as a result of an unrecorded plant by a mosquito abatement group. Lake 3 contains the same fishes as Lake 4, with the exception of the rainbow trout.

No fish were planted in either the Oxidation Pond or Lake 2, but the latter was found to contain bluegill sunfish, threadfin shad, mosquitofish, and green sunfish, Lepomis cyanellus. These fish probably managed to come down the line from Lake 3, since Lake 2 was "downstream" in 1962. The source of the green sunfish is unknown, but may have been among the bluegill sunfish that were put in Lake 4. The operation of Lake 2 was changed in 1963 to make it a secondary oxidation pond not adaptable for fish.

Test seining was conducted on 3 days during 1962 and 1963. The results of this seining catch and composition are plotted in Figure 23. This seining also developed information about growth of fishes, distribution of fishes among the lakes, evidence of reproduction, and an estimate of the standing crop. Length frequency data are shown in Table 25. Growth of the redear sunfish in Lake 3 was limited from October 1962 to August 1963. The median size shifted by only 0.2 inch. The average size of the redear sunfish was about 4.8 inches. In Lake 4 the modal length for fish increased 0.6 inch from 1962 to 1963. The average size in Lake 3 has been consistently larger than in Lake 4. Crowding and competition for food are considered responsible for the smaller size of the redear sunfish in Lake 4. The threadfin shad in Lake 3 show a considerable growth rate, but this is probably related to the selective mortality during the December 1962 fish kill. As shown in Figure 23, this kill greatly decreased the population. The length frequency data for threadfin shad in Lake 4 also show an increase in modal size and a decrease in relative numbers. The threadfin shad are decreasing in both lakes.

The length frequency data for the largemouth bass show that the bass have responded well in both ponds and that good growth in size

Table 25. MODAL SIZE OF FISH IN inches.

Date	Largemouth Bass	Threadfin Shad	Redear Sunfish	Bluegill Sunfish
		LAKE 3		
6- 6-62			3.8	
10-22-62		1.4	4.6	
8-12-63	2.5 and 13	2.6	4.8	3.4
		LAKE 4		
6- 6-62			2.8	
10-22-62		1.8	3.6	
8-12-63	4.0	3.2	4.2	

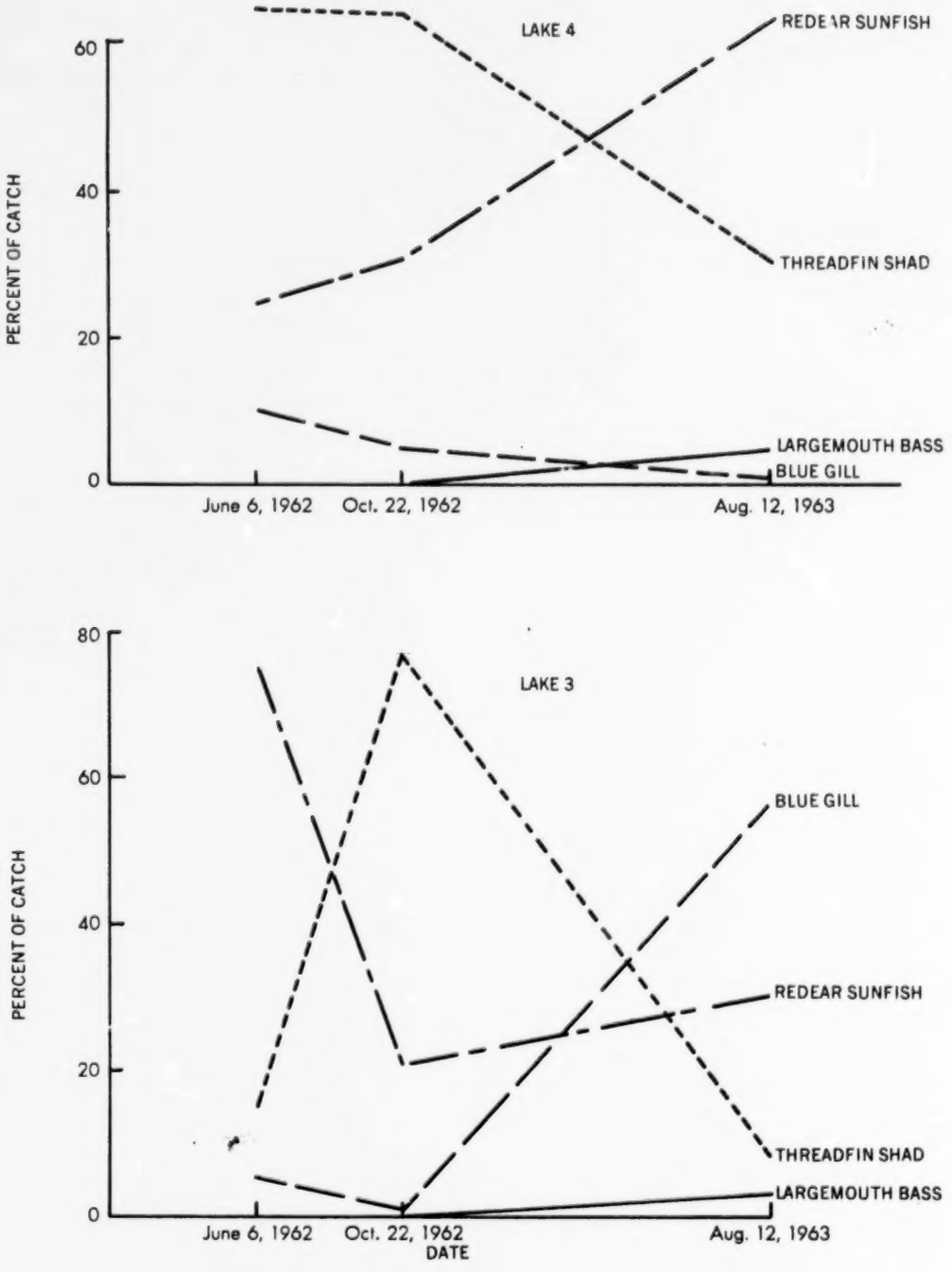

Figure 23. Composition of fish seining catch.

and numbers has resulted. Also noted is the good growth of bluegills in Lake 3.

All the various species have now spawned except the channel catfish and rainbow trout. An estimate was made of the standing crop of fish in Lake 4. This followed seining procedures in which approximately an

acre area of the lake was seined with a 400-foot net. Subsamples of this catch were used to obtain a calculated weight of about 400 pounds per acre. This would mean that in Lake 4 approximately 4,400 pounds of fish are present. It should be noted, however, that this crop is due to a large number of small panfish and threadfin shad, with relatively few predator fish. Figure 23 shows that there may be some tendency to equalize this ratio of the predators to the forage fish. With the change from the limited "Fishing for Fun" program to "Selective Removal" fish program, an accelerated equalization in this ratio may result. The fishing program has been unsuccessful as far as a balanced sport fishing program is concerned. It may be necessary to plant additional numbers of bass in both ponds in order to provide an optimal fishing program.

A major fish kill occurred in December of 1962 in Lake 3 — it was estimated that at least 10,000 shad died. Subsequent seining revealed only a few shad remaining in the pond; but, as indicated in Figure 23, recovery has been good. Most causes for the fish kill could be ruled out since water from Lake 3 is derived from Lake 4 and in turn flows into Lake 2. No fish died in either of the adjacent lakes although a later smaller die-off of shad in Lake 4 was noted. No other species of fish died. Temperature was a possible cause. One unusual biological event was noted during the fish kill: a bloom of bryozoan statoblasts. Some laboratory work with bryozoan statoblasts showed toxic effects on test shad, and this may be the reason for the fish kill. The loss of shad was evidently not serious since subsequent sampling illustrated the ability of the shad to reproduce abundantly and to grow adequately again in this environment.

Although the water for the recreation lakes is derived from domestic sewage, the degree of treatment before the water reaches the lakes appears adequate to provide a suitable-quality water for fish life. Although very large removals of nutrients have been obtained, the still nutrient-laden reclaimed water does promote growths of algae sufficient for fish productivity in the lakes. Copper sulfate has been used in attempts to control the filamentous algae that attaches to the bank; but more recently this algae has been removed by physical means. Dissolved oxygen concentrations and temperatures have been satisfactory for all fish planted.

In 1964, on one weekend, a trout was caught and returned to the lake, indicating that these fish have also survived. Attempts will be made in the future to provide some form of shelter so that the catfish may spawn.

OTHER AQUATIC OR SEMI-AQUATIC VERTEBRATES

Other aquatic vertebrates, besides fishes, found at the project, include increasing numbers of bullfrogs, Rana catesbeiana, and birds. The following birds have been recorded:

Podiceps caspicus	-	eared grebe
Podilymbus podiceps	-	pied-billed grebe

Ardea herodias	-	great blue heron
Butorides virescens	-	green heron
Casmerodius albus	-	common egret
Nycticorax nycticorax	-	black-crowned night heron
Branta canadensis	-	Canada goose
Aix sponsa	-	wood duck
Anas platyrhynchos	-	mallard
Anas cynaoptera	-	cinnamon teal
Oxyura jamaicensis	-	ruddy duck
Athya affinis	-	lesser scaup
Botaurus lentiginosus	-	American bittern
Totanus flavipes	-	lesser yellowlegs
Micropalama himantopus	-	sandpiper
Charadrius vociferus	-	killdeer
Steganopus tricolor	-	Wilson's phalarope
Fulica americana	-	American coot
Larus delawarensis	-	ring-billed gull
Larus argentatus	-	herring gull
Sterna forsteri	-	Forster's tern
Thalasseus maximus	-	royal tern
Sterna hirundo	-	common tern
Hydroprogne caspia	-	Caspian tern
Megaceryle alcyon	-	belted kingfisher

There are also a number of other species that have not been identified.

There are several reasons why bird life at the recreation lakes is worthy of some attention. First and foremost is the influence that some of the waterfowl have upon the coliform counts. The coots have established a winter residence at the lakes, and their numbers at times exceed 400. Since coliform bacteria counts are used as an indication of pollution, or conversely of the degree of waste treatment achieved, a source from other than the treated effluent can result in some very misleading figures. In addition, the coots have been very instrumental in destroying the grass cover along the shoreline and in creating a nuisance because of their droppings, which are everywhere. Fortunately, the coots depart before the increased summer use of the recreation area.

Another aspect of aquatic bird life at the lakes is the effect that certain forms may have upon the fish life. Many of the species thus far recorded will readily eat fish, either dead or alive, and when fish populations are concentrated, a significant loss of fish could result.

Beneficial effects occur when emergent insects are eaten on the wing by flocks of cliff swallows flitting over the surface of the Oxidation Pond.

The detergent concentrations, particularly in the Oxidation Pond, have seemingly not been detrimental. Several types of birds inhabit the pond throughout the year and when "water fleas" congregate near the surface, they are eaten with apparent relish by the ducks.

Finally, there is the aesthetic aspect of the lakes. For many people, the observation of bird life provides an excellent form of recreation. Although newly created bodies of water will obviously attract aquatic birds, the numbers and kinds of birds are both an advertisement for the quality of the water and additional publicity for the attractiveness of the area.

EPIDEMIOLOGICAL STUDIES

During October and November 1963, 55 families in the Santee area were surveyed by the California State Department of Public Health. The survey was designed to determine whether or not users of the Santee lakes suffer from an increased amount of minor illnesses as compared with those who do not use the lakes. Thirty-nine familes kept complete day-to-day records noting on each day illness of any kind in each member of the family.

At the same time, a registration of persons coming to the lakes was made for each weekend when the lakes were open. This record showed that the average attendance was 286 people per day during the time of the study. Fifty-five percent of these were children and 50 percent of the registrants came from Santee. The registration also showed that approximately 35 percent of those in attendance came from the same area in which the minor illness survey was made.

The only significant information that developed from the survey was a relationship between the number of sick days reported and the age of the individual reporting. As would be expected the young age groups were found to have more minor illness than those in the older age groups. No significant relationship was developed between dates of the lake visits and the days of the illness. No significant difference was shown in the number of sick days reported between those persons visiting the lakes and those who did not visit the lakes.

In August 1964 a review of this record and all of the associated studies was made by a Special Epidemiological Advisory Committee for the Director of the California State Department of Public Health. This committee recommended that the recreation program be expanded to include swimming in a separate area and under the same degree of surveillance as has been used for this study.

DISCUSSION

In determining the fate of viruses as well as other public health and biological aspects concerned with the recreational use of waste water at Santee, a detailed summary of sewage characteristics and treatment procedures has been obtained. This record shows that the 12,000 people at Santee require about 3,000 services and contribute a flow of 75 gallons per capita per day. Table 26 summarizes physical and chemical increments that are added to the waste-water flow. The

Table 26. WASTE-WATER INCREMENTS ADDED TO THE FLOW AT THE SANTEE PROJECT[a]

	lb/day per 1,000 people	
Volatile suspended solids	320	
Fixed suspended solids	50	
BOD	190	
COD	700	
Total nitrogen	38	
Orthophosphate	39	
Chloride	70	(above water supply) (at 95 mg/liter)
ABS	10.7	
Total dissolved solids	240	(above water supply) (at 750 mg/liter)

[a] Coliform at MPN = 49 x 10^6/100 ml and flow 0.9 mgd for the population of 12,000 = 140 x 10^9 per person/day.

median coliform concentration based on the above population and rate of flow shows that contribution per capita is 140 billion coliform per day. The BOD concentration of 190 pounds per thousand persons per day appears normal when consideration is given to the use of garbage grinders in homes. Other increments may appear high but are probably related to the high waste production from "our effluent society." Increments of chloride are related to considerable softener recharge applied to the 300-milligrams-per-liter-hardness water. Several small laundrys and a geriatric hospital occupy the area, but there is no industrial discharge that could affect the waste-water quality.

The weather record during the study showed slightly below normal rainfall, although runoff did occur after concentrated rainfall during the first year. Temperatures equaled the high for the period of record and were within 3 degrees of the recorded low. The variation between summer and winter temperatures does not appear to affect the conventional treatment processes. The temperatures do affect the Oxidation Pond and stream and may have been a cause of a threadfin shad die-off.

The treatment processes at Santee include an activated-sludge process, a pond, an intermittent sand filtration process, and chlorination that could be varied as to the point of application and rate. It was also discovered that the stream resulting from the recovered ground water flow performed a treatment function. Reductions of pollution as measured by selected water quality indicators through the various treatment processes are shown in Figure 24. The activated-sludge treatment process appears normal for the removal of BOD and suspended solids but may be below normal for removals of COD. Of note were occasional very low orthophosphate residuals. The lower residuals usually occurred at colder temperatures. The use of the activated-sludge process to exploit control of phosphate in waste water may be appropriate.

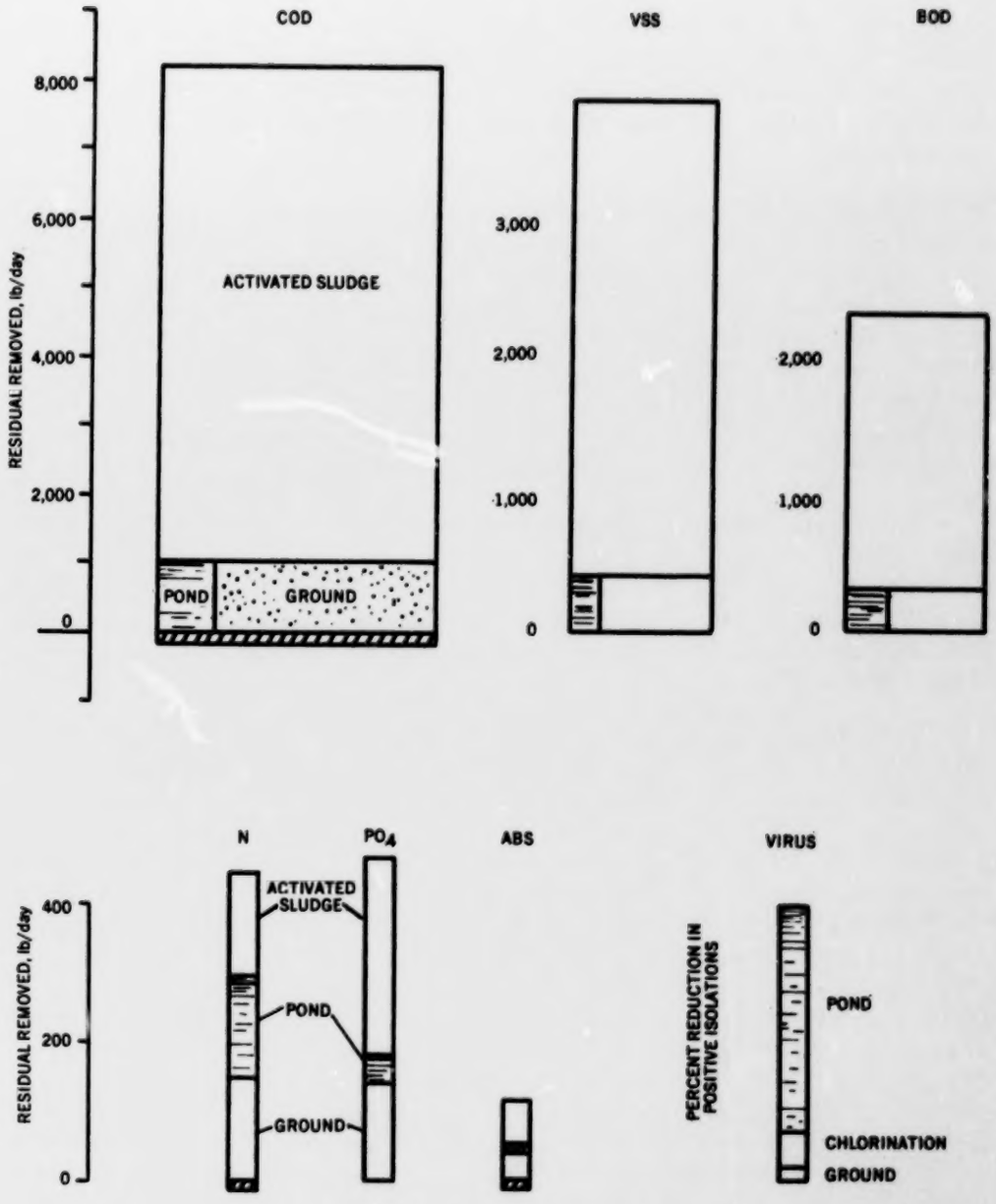

Figure 24. Treatment system removals.

The pond, as a treatment device, was effective in providing good removals of nitrogen, bacteria, and virus. It should be noted that the pond was loaded at very low rates of 22 pounds of BOD per acre per day and that the carbon-nitrogen ratio was adverse for optimum photosynthesis. Dissolved oxygen measurements show the pond operates satisfactorily most of the time but was subject to upsets, especially during the fall and winter. During these periods, blooms of algae would die off or be consumed by zooplankton and low dissolved oxygen concentrations were apparent. When temperature drops occurred at these times, up-welling of bottom waters would occasionally cause odor

conditions. The increase in ammonia nitrogen at these times would inhibit the regrowth of algae. The storage provided by the pond was effective in reducing the number of virus identifications and could generally justify the use of a pond when subsequent water use was contemplated.

Although concentrations of phosphate coming out of the pond show little average reduction, some removal did occur at times, and because of loss of about 10 percent of the flow through percolation from the bottom of the pond, a net reduction did occur. The spreading area was an effective treatment device when the area could be operated within reasonable flow limits. At high flows, or when water was spread for more than about 24 hours, the water table would build up under the spreading area. This reduced treatment effectiveness and resulted in breakthrough of phosphate and ammonia nitrogen.

The stream as a treatment device provided removals of both phosphate and ammonia nitrogen even though the reach of the stream was effective for only 2,500 feet. Only one large concentration of phosphate was measured at the inlet to the lake. The mean concentrations of total nitrogen and total phosphate that reached the lake have remained less than 2 ppm each.

The effectiveness of the ground for control of coliform was not affected by prechlorination. Approximately the same concentration of coliform, fecal coliform, and fecal streptococci organisms were found with or without prechlorination. The long path of travel through the aquifer was, however, effective in reducing all bacterial counts to very low levels. Figure 13 shows that the recovered waters at the inlet to the lake had ratios of fecal coliform/coliform and fecal streptococci/fecal coliform considerably different from that of a normal sewage effluent or the Santee effluent. These ratios of bacterial densities could arise from soil, animals, and birds, or could result from recovery or regrowth of inadequately "killed" organisms. Again, with chlorination of the recovered ground water flow, the lake waters were either recontaminated by soil, birds, or animals, or the waters cultured the regrowth or recovery of the three indicators to approximately the same levels as without chlorination. Since chlorination was much more effective at the lake inlet, the chances for recovery or regrowth would be very low, and lower levels of the indicator organisms would be expected. The effects of recontamination can also be verified by a comparison of ground water samples obtained from the ditch or from a pipe inserted into the saturated zone of the aquifer. Bacterial densities in the ditch at location 6. 2 were always much higher than the very low counts obtained from the pipe. In spite of the recent history of the subject waste water, recontamination by the soil, birds, or animals would appear to account for the major portion of the bacterial densities in the recreational lake waters.

Viruses were not found in either the lake inlet or outlet waters and were identified in only about 16 percent of the Oxidation Pond samples. With the record of 100 percent virus identification in the raw sewage

samples and 96 percent in the activated-sludge effluent samples, it can be concluded that the pond and percolation systems were effective barriers to transmission of virus. The moderate blooms of the diverse phytoplankton found in the recreation lakes are typical of rich, natural waters. Occasional high and low algae populations were encountered, and these can be related to changing flow and nutrient levels. The concentrations of phytoplankton have not interfered with the boating or fishing activities, although some of the attached forms such as Cladophora may be aesthetically undesirable to some people. The moderate turbidity does benefit the lakes in the restriction of rooted aquatic growth in shallow areas. Some evidence indicates that the removal of nitrogen to concentrations of less than 1.0 milligram per liter has provided the impetus for blooms of blue-green algae such as Anabaena in Lake 3. These blooms then cause re-enrichment with organic nitrogen by fixation of atmospheric nitrogen. These blooms are limited by the orthophosphate concentrations. Their importance is related to the nuisance caused by the formation of surface scums.

Zooplankton populations have developed in both lakes to the level that provides for a good consumer-producer relation. Since the productivity of the forage fish in the lakes accounts for most of the weight of 400 pounds per acre now present, the increments of both phytoplankton and zooplankton produced indicate an adequate relation exists between primary producers and consumers. The predator fish population has not yet developed to the proper predator/forage ratio to make the fishery a complete success.

Benthic organisms in the lakes have also developed a position in the food chain without creating a nuisance condition. Benthics in the oxidation ponds and other waterways leading to or from the lakes are the major problem, though the gnats have not reached the nearby homes in numbers sufficient to cause a serious condition. The control of mosquitoes has required both mosquitofish and the use of larvicide sprays.

The investment in the recreational lakes at Santee now equals slightly less than 20 percent of the total investment in sewage treatment and waste-water reclamation as shown in the following summary prepared from the Santee County Water District records:

Sewage treatment plant investment	$ 424,884.22
Water reclamation	62,533.16
Furniture & equipment less depreciation	991.90
Recreation area	124,797.95
Total	$ 613,207.23

Operating costs for the water reclamation portion of the process, which includes pumping, percolation, and chlorination, equal about $25 per acre-foot.

ACKNOWLEDGMENTS

The objectives of this study were originally outlined by staff members of the U. S. Public Health Service, the California State Department of Public Health, and the San Diego County Department of Public Health.

Continued assistance in planning the studies and collecting the data has been provided by the many personnel of the above agencies, along with the staffs of the other agency members of the Advisory Group. These are the California Department of Fish and Game, California Department of Water Resources, California Water Quality Control Board, and the Santee County Water District.

Occasional assistance in collection of field data along with certain laboratory analyses have also been provided by employees of the San Diego Regional Water Pollution Control Board and the Testing and Control Division of the San Diego Utilities Department.

Special recognition is given Roderick F. Bott of the San Diego Department of Public Health, Paul C. Ward and Harvey Magy of the California State Department of Public Health, Lee Miller of the California Department of Fish and Game, Ray Stoyer of the Santee County Water District, and Paul Eastman of the U. S. Public Health Service, for their individual contributions and advice in preparation of this report.

APPENDIX

SANTEE WATER RECLAMATION PROJECT

MEMORANDUM OF UNDERSTANDING

April 13, 1962

I. The following agencies: United States Public Health Service, California State Water Pollution Control Board, California State Department of Public Health, California Department of Water Resources, California Department of Fish and Game, San Diego County Department of Public Health, and Santee County Water District, agree that the currently operated sewage treatment and water reclamation facilities of the Santee County Water District present an ideal opportunity for studying the reuse of waste water for recreational and recharge purposes. These agencies therefore have agreed to join in a cooperative study to be known as the "Santee Water Reclamation Project." Each agency shall have at least one representative on a Project Advisory Committee which will guide the project.

II. Contributions of resources by each of the above agencies to this project in fiscal years 1961-62 and 1962-63 shall include but not be limited to the following:

A. The United States Public Health Service agrees to provide:

1. The project coordinator, available as necessary,
2. The project report, including a monthly summary of accomplishments,
3. Support for certain aspects of the project, including weekly chemical and biological analyses and consultation on aquatic biological aspects,
4. Support, if necessary, for enterovirus determinations in the San Diego County Health Department laboratory,
5. Assistance and technical support as necessary from the staff of the Sanitary Engineering Center at Cincinnati, Ohio, and
6. Support to the Santee County Water District to make beneficial changes in the percolation area to provide for optimum treatment of the waste waters.

B. The California State Department of Public Health agrees to provide:

1. A mobile laboratory with two chemists and a laboratory assistant to perform the four-hour cycle of bacterial and

related chemical determinations for two-week periods, four times per year, on or about the first of February, May, August, and November.

2. An epidemiology traineeship (as M. D.) assigned full-time to the project to make an epidemiological study of recreational users at the Santee Lakes.

3. Radioactivity determinations as frequently as the project coordinator decides to be necessary, and

4. One-fourth to one-half time of a vector control technician.

C. The California State Department of Water Resources agrees to provide:

1. Assistance for sampling transportation and chemical analyses during each of the two-week periods the State Health Department mobile laboratory is on the site,

2. A ground water – hydrology study of the Sycamore basin,

3. A flow rating device and two water stage recorders as required on the project, and

4. A recording conductivity meter for monitoring of water quality during the intensive two-week sampling periods.

D. The California Department of Fish and Game agrees to provide:

1. General assistance in the fish management program,

2. Fish for stocking purposes and study as needed and as the supply will permit,

3. Fish handling equipment including nets, etc., and

4. Assistance in sampling fish and other aquatic organisms as time, personnel and equipment will permit.

E. The San Diego County Department of Public Health agrees to provide:

1. Office space and stenographic services for the project coordinator and epidemiologist trainee,

2. Laboratory analyses for coliform, fecal coliform and fecal streptococci for the eight weekly samples obtained from various locations in the project during the intervening periods between mobile laboratory assignments,

3. Laboratory studies of enteroviruses in the sewage and waste water in accord with recommendations of the technical advisors to the project within the capability of the support of the California Water Pollution Control Board and United States Public Health Service,

4. Field and laboratory examinations for gnat and mosquito larvae at possible two-week or weekly intervals during their growing season, and

5. Transportation of all samples from Santee to the laboratory.

F. The Santee County Water District agrees to provide:

1. Access to and the use of the sewage treatment and water reclamation facility including the spreading grounds and recreational lakes for the research study,

2. Working space, water, electric and waste water services as necessary for the mobile laboratory or other on-site tests performed in this study.

3. All bacterial and chemical sample collection and gage height and flow measurements at four-hour intervals during each two-week intensive sampling period and weekly during the intervening periods,

4. Operating changes in the treatment procedures or facility according to the Research Plan or when significant results of laboratory analyses make a change desirable to provide new data,

5. Records of plant operation including flow records and operating changes and results of any field tests performed by plant personnel,

6. Assistance in establishing additional wells to monitor ground water movement and quality, and

7. Assistance to the technical staff in the various activities associated with the project.

III. The proposed research program has the overall goal of utilizing the sewage reclamation plant and recreation facility operated by the Santee County Water District to provide information regarding the degree of treatment necessary to make a reclaimed water suitable for recreational use, replenishment of ground water, and other possible beneficial uses. The agencies participating in the project agree, however, that any beneficial changes in the research program that can be provided by increasing the number of participants or the range of research will be acceptable.

GPO 823-046-7